GUIDE BOOK

Fourth Annual Field Conference

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS

BANFF-GOLDEN-RADIUM

August 1954

Ian Coule

BOOK SALE
$5

Frontispiece

Floe Lake from the north, illustrating the "Rock Wall" on the east face of the Vermilion Range. The wall is composed of the Upper Cambrian Ottertail limestone. The cliffs on the right are 2000 feet high, the beds dipping about 25 degrees away from the observer. Photograph by Hal Bavin.

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The Alberta Society of Petroleum Geologists and the Field Trip Committee are indebted to the many people who have assisted with the field conference and in preparation of this guide book. The efforts of those who are named here, and others who have not been named, are greatly appreciated.

Special thanks are also due to the Companies listed below for the essential part they are assuming during the field conference:

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PREFACE

The advent of the fourth annual field excursion of the Society has presented the opportunity of publishing another guide book of which, we feel, we can be proud. When the route to be followed during the conference was chosen, we were of the opinion that little material would be available for this volume, aside from a resume of the older works covering parts, which had been mapped, of the area. Such a summary would assuredly be worthwhile, but a more complete coverage and an injection of new material seemed highly desirable. Fortunately, our misgivings have not been realized, and we believe that, thanks to our contributors, the book contains a suitable balance of new and old knowledge. In fact, our contributors have made it possible to present an account of the geology of the southern Rocky Mountains of Canada, which, far from complete though it be, makes available new and original thinking regarding the stratigraphy and structure of this complex area, as well as providing summary descriptions, based partly on older works, of the igneous rocks and mineral deposits. The guide book is accompanied by a tectonic map of the region, which is a compilation of the best available information. The map is easily the most complete so far published. Also provided are extensive references to pertinent literature.

The discussion here of the geology of the area is perhaps the first attempt at a detailed comprehensive treatment of the southern Canadian Rocky Mountains. It is hardly necessary to remind the reader that a highly critical attitude should be maintained. The large area under discussion has not been mapped in its entirety, and if it had, there would remain plenty of scope for individual opinion regarding the stratigraphy and tectonics. The editors believe that an outstanding job has been done by Henderson and North; however, they are agreed with them that there is ample room for other work and interpretation. The structure section across the Flathead valley, presented by Clark, provides an interpretation of the tectonics at the south of the map-area, also based upon the kind of critical appraisal of geological evidence that is advocated. The conclusions reached by these authors could all be wrong in whole or in part, but further progress toward a complete understanding of the geology of the region is dependent upon such an attitude.

We have been fortunate in obtaining contributions from authors with new material, but it is fitting that we have some representation, no matter how brief, of previous workers of note. J. A. Allan, Professor emeritus of the University of Alberta, and C. S. Evans, Union Gas Company of Canada, Ontario, have kindly contributed. A summary of Allan's former work on the Ice River Complex appears on page 141 of the book. Evans has presented his impressions of the work of North and Henderson, based on his own earlier work in the area, in a foreword immediately following. The contributions of other authors were not available to him for comment.

The editors are satisfied that all of our authors have made useful, stimulating, and instructive contributions. Our thanks and those of the Society are wholeheartedly proffered to them.

The contents of this book, we feel, will serve a useful purpose long after the field trip is over. Specifically, it will be possible, with it as guide, to retrace the route in the future and each time achieve some further understanding of the geology. Most readers will benefit by the discussion of a part of the geologic column, and of a geologic province, not now normally part of their routine. The consideration of both structural and stratigraphic problems relating to the area will undoubtedly prove more helpful that at first realized in the study of problems related to the plains and foothills.

J. C. Scott

F. G. Fox

PREFACE

The advent of the fourth annual field conference of the Society has presented the opportunity of publishing another guidebook [illegible] followed during the conference [illegible] be available for this volume [illegible] of the older [illegible] been mapped [illegible] of the area. Such a summary would [illegible] plete coverage [illegible] [illegible] formation. [illegible] references to pertinent literature.

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We have been fortunate in [illegible] [illegible] of Cerrillos [illegible] Grant [illegible] on page 44 of this book [illegible] North and Hendrickson [illegible] following. The contributions of other [illegible] were not available in time for inclusion.

The editors are satisfied that all [illegible] tive contributions [illegible]

The contents of this guidebook [illegible] will serve a useful purpose [illegible] over. Specifically, it will [illegible] [illegible] discussion [illegible] part of the [illegible] of their [illegible]. The consideration of both structural and [illegible] problems relating to the area will undoubtedly prove more helpful [illegible] in the structural problems related to the plains and foothills.

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FOREWORD

Your editor asked me to write for this guide book, even if it were only anecdotal, about my field work in the Dogtooth and Brisco Ranges in 1925-1927. That he gave me this latitude proves that he is a man of very great understanding, for it is difficult for this geologist to keep many of the details of his own work, let alone that of others, in his mind after an absence of nearly thirty years from the area under discussion.

As I have read over the manuscript of North and Henderson, referring to my own publication to refresh my memory, I have been almost overcome by an urge to revisit not only my former area, but many other places along the Trench and in the Rockies. I know of no better place where, for hard physical work and the use of all the mental abilities one may have, there can be greater satisfaction in working out some of the problems of stratigraphy and structure. This satisfaction is entirely aside from the purely extrovert satisfaction of getting to the highest peak and the aesthetic appreciation of the scenery.

North and Henderson have dealt with many parts of the Rockies that I have never seen, but it appears to me that they have integrated a quite considerable amount of field work of their own, with a great amount of critical examination of the reports of other workers, from which they have been able to discard quite a bit of chaff, some of which, I am afraid, was provided by myself.

To show that I have read and re-read the manuscript I should make some remarks to prove it. However, I always have loathed forewords to publications that summarized the story and gave away the plot. So I will just say here that the conclusions of the authors on the thicknesses of Palaeozoic strata in the Rockies; their view on a Rocky Mountain geosyncline; their observance of erosion in very intriguing places, the manner in which some faults intersect other faults; and the manner in which apparent confusion of thrust and normal and other types of fault have been resolved to present a logical explanation of a certain feature; have made very interesting reading and have made possible a much better understanding of the stratigraphy, structure, and history of this geological province.

I like their straightforward statement of opinions, opinions that are the best available at this time, with their recognition that detailed field work in certain areas may require later modifications of these opinions.

It is a vast area, and no one man can transverse and climb all of it, let alone answer all the problems. The authors, while giving by far the best and most comprehensive report as yet to appear on the Rocky Mountain Trench and the Rocky Mountains, do not pose as being infallible pundits. In this age of superlatives, I wish to underline my opinion of their work by saying simply "I like it."

Speaking of pundits, and referring back to anecdotes, I cannot refrain from recounting the following:

There was the time when an internationally known palaeontologist, not Dr. Walcott, visited me in the field, and to my horror collected fossils up the slope in utter disregard of overturned beds and stratigraphy, having perfect assurance that he knew the fossils so well that none of that mattered.

Then, again, in measuring a long and rather difficult section in the Dogtooth Mountains, through the basal Cambrian quartzites upward into limy beds where Lower Cambrian fossils were found, I came then into some beds in which only one type of fossil was found. I didn't

know what it was since it appeared to have the symmetry of both the pelecypods and brachiopods. Some distance above this, again, undoubted Lower Cambrian fossils were found. I shipped this unknown fossil to the East and three weeks later was informed that it was a Devonian pelecypod. So back I went to the same section, where I checked my former conclusion that the lower quartzites were certainly right side up, but found that it was a little more difficult to resolve the section of the upper limy beds on purely stratigraphic evidence. However, on the second repeat, we found this fossil firmly plastered on to an *Olenellus.* That relieved the tension, which was completely dispelled some time later by a communication from the Smithsonian Institution that they were pleased to see that the Lower Cambrian brachiopod "Rustella" had been found in my section.

All this added to my great respect for that man "Strata Smith."

There are many anecdotes concerning the area more interesting than these but none seem to fit the occasion as well as these. I wish to thank your editor for the opportunity given me to make these remarks, and wish for everyone making the trip a pleasant and fruitful interlude.

CHAS. S. EVANS,
Chatham, Ontario.

THE KEYSTONE OF THE CANADIAN ROCKIES

H. H. BEACH[1]

The Banff Windermere Highway, the Columbia River between Radium and Golden, and the main line of the Canadian Pacific Railway between Golden and Mount Eisenhower, outline a keystone-shaped area of approximately 550 square miles, straddling the Continental Divide in the heart of the southern Canadian Rockies. The area is truly deceptive. Even the most calloused world traveller is awed and inspired by the natural beauty of the rugged terrain. With good reason, Lake Louise has been included in a listing of the world's seven perfect landscapes. Yet, the spectacular glimpse one has of the Columbia Valley through Sinclair Canyon and the soft pastoral beauty of the Rocky Mountain Trench at Columbia Lake, certainly merited consideration. What the casual traveller fails utterly to appreciate is the remarkable history of the region in the one hundred and fifty years that it has been known to the white man.

The Keystone area has long been a mecca for learned men from all over the world. Paradoxically, the true greatness of the area lies not in its loveliness, but in the challenge and stimulus it has given to men's minds. The record of contributions in basic concepts of the natural sciences and engineering that have been made here is not surpassed in another rural area of comparable size in the Dominion of Canada.

THE LAY OF THE LAND

For a proper understanding of the history of the region, one should have in mind the essential elements of the topography. Columbia River flows northward for some 200 miles from its source in Columbia Lake, to form the west side of our keystone. Thence after rounding "The Big Bend," it continues southward into the State of Washington to empty into the Pacific Ocean at the city of Astoria. The broad valley of its northward course between Windermere and Golden, has long been recognized as a part of the Rocky Mountain Trench, the great valley that extends with only minor interruptions from northwestern Montana to southern Yukon at the western edge of the Rockies. The north side of the keystone is marked by the roaring Kicking Horse River flowing westward from the Continental Divide to join the Columbia at Golden. The Kicking Horse River is closely paralleled by the main transcontinental line of the Canadian Pacific Railway. The Windermere Highway, extending across the western ranges of the Rockies from Mount Eisenhower to Radium, delineates the southeastern side of the area. The Sinclair Summit, over which the south end of the road crosses the Brisco Range, has been a fundamental travel way only in the last thirty or forty years. It would be more appropriate in outlining an area of historical entity, to place the southern end of our keystone at Canal Flats where the south flowing Kootenay River leaves the Rockies to continue its course along the Rocky Mountain Trench into Montana. It is notable that the Kootenay comes within two miles of joining the Columbia at the south end of Columbia Lake. After this "near miss" the Kootenay must flow another 300 miles before effecting its ultimate junction with the Columbia at Castlegar, British Columbia. One gets the eerie feeling that just by stamping the feet at Canal Flats, the junction could be effected.

The area within the keystone thus outlined is an almost impenetrable vastness of rugged mountains. The total relief approaches 10,000 feet. Elevations along the floor of the Trench between Canal Flats and Golden, vary little from a mean of 2550 feet above sea level. Notably, this elevation is 1000 feet lower than Calgary, well out on the plains east of the Rockies. The terrain rises abruptly over six thousand feet at the east wall of the Trench to the crest of the Brisco-Beaverfoot Range. The eastern slopes of the range drop almost as abruptly into the Kootenay valley. Eastward from the Kootenay, the surface again rises to the summit of the Vermilion-Michell Range, with peak elevations over 10,000 feet above the sea.

[1] Assistant Manager, Texaco Exploration Co., Calgary, Alberta.

A third, and culminating step, after a rapid descent into the Vermilion River valley, is the rise to elevations exceeding 11,000 feet along the Continental Divide Range, the backbone of the Rockies. Two mountain giants, Mount Assiniboine and Mount Hungabee (the Chieftain), dominate this great ridge with elevations respectively of 11,870 and 11,457 feet above sea level.

It is understandable that the great Cordilleran ice cap which, in Pleistocene time, blanketed the entire area of the central Rockies, finds its last retreat among the crags of the Continental Divide. The ice comprising these glaciers is truly a fossil ice. In the thousands of years of slow compaction, its crystal structure and optical properties have undergone subtle changes. In certain lights, the birefringence of the crystals creates plays of color reminiscent of tropical butterfly wings. It is no exaggeration to say that the divide area includes some of the world's finest mountain scenery.

THE HISTORICAL SETTING

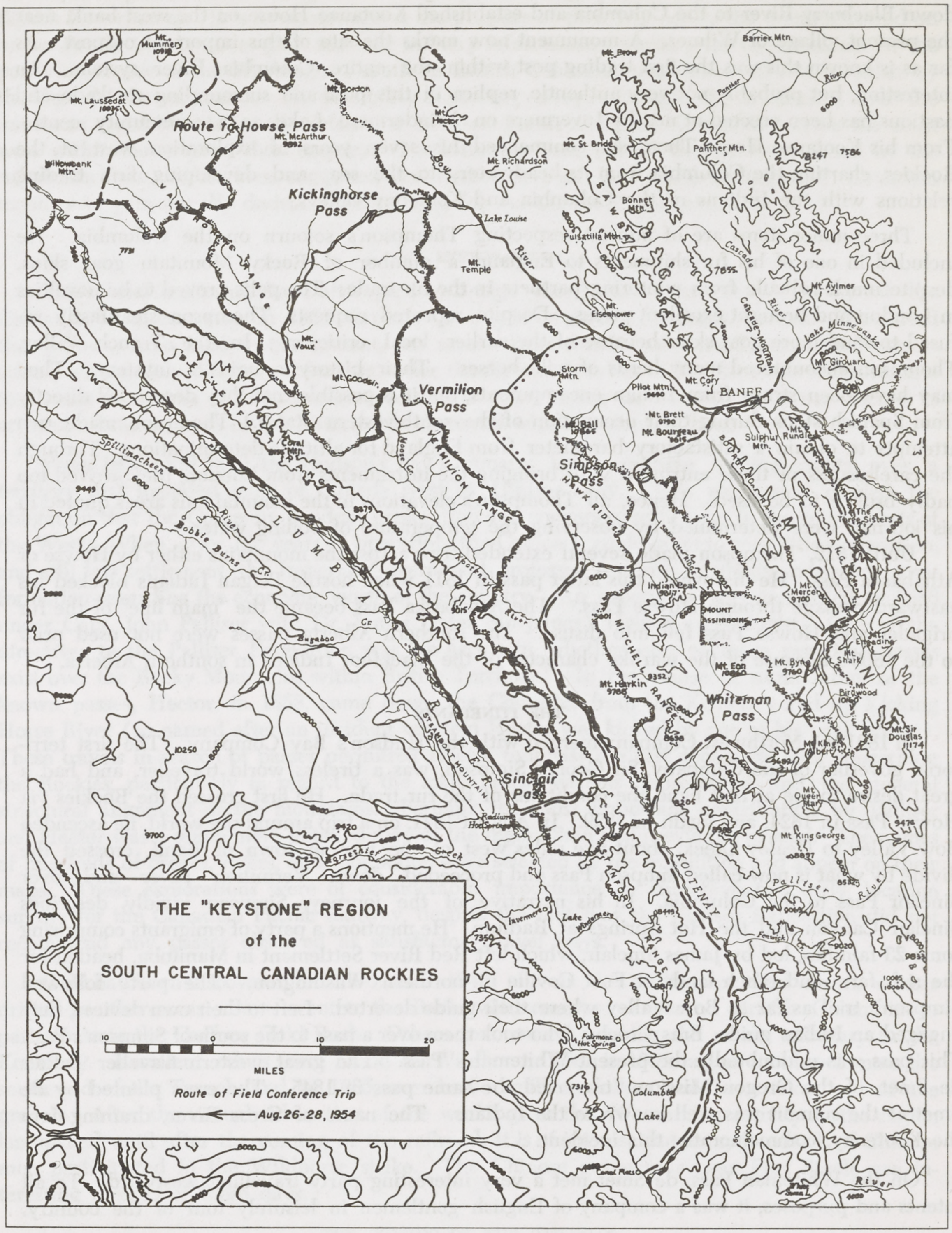
Visualize the state of Canada one hundred and fifty years ago. Two great organizations, the Hudson's Bay Company and the Northwest Company, were battling for control of the fur trade, the dominant industry of all Canada. It was much the most intense rivalry that the commercial world has yet experienced. With a ready market in Europe for the furs, it was "big business" by any standard. The only depressing aspect was realization that as large a market for furs, or even larger, existed in China and neighboring areas of oriental culture. It was with no mere thought of exploratory prowess that so many vain attempts were made to find a northwest passage around the north side of the continent—a practical route to China. It was not idealistic curiosity that drove men to search exhaustively for any traversable pass across the barrier of the Rocky Mountains, for such a pass would have a place in the economy comparable to the transcontinental railroads of today. It is notable that only twelve satisfactory passes have yet been found through the 400-mile length of the Rockies bordering Alberta. Two are in the Crowsnest region, five in the Jasper-Smoky River region, and five in the general area under discussion. These latter are from south to north: the White Man, the Simpson, the Vermilion, the Kicking Horse, and the Howse. Actually, Howse Pass is just north of the Keystone area, forming a link between the headwaters of the Saskatchewan and Boat Encampment at the apex of the Big Bend of the Columbia. For years it was the most important travel way of all. Boat Encampment was referred to in the early records as the half-way point between Hawaii (then the Sandwich Islands) and London, England. It is not too difficult to visualize the Keystone area with its concentration of traversable passes as literally the Grand Central Station for travel westward from the Plains to the Pacific.

All of the passes were known to the Indians, and all, with the probable exception of the low swampy Crowsnest Pass, were used by them. The Kootenay Saleesh and Shuswap Indians lived on the west side. The Kootenays used to go out into the plains to hunt the buffalo herds for food, and the Plains tribes would cross back in warlike array to punish the intruders and steal their horses. A vivid record of one such battle is painted on a stone cliff face, just back from the east shore of Columbia Lake[1]. It is also evident that the plains Indians had a vital interest in preventing the white man from selling guns to the west side Indians. Thus, it took consummate courage for the white man to cross the Rockies and extend the domain of the fur trade and, incidental thereto, knowledge of northwestern America.

THOMPSON'S TRAVELS

Alexander Mackenzie had completed his historic overland trip up the Peace and across the Rockies to the Pacific in 1793. David Thompson, the master geographer of the Northwest

[1] The writer was directed to these interesting drawings by Dr. J. D. Weir of Calgary.


THE "KEYSTONE" REGION
of the
SOUTH CENTRAL CANADIAN ROCKIES
MILES
Route of Field Conference Trip
Aug. 26-28, 1954
Route to Howse Pass
Kickinghorse Pass
Vermilion Pass
Simpson Pass
Whiteman Pass
Sinclair Pass
BANFF
Lake Louise
Mt. Mummery
Mt. Laussedat
Mt. Gordon
Mt. McArthur
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Mt. St. Bride
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Mt. Prow
Barrier Mtn.
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Mt. Temple
Mt. Aylmer
Mt. Eisenhower
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Lake Minnewanka
Mt. Brett
Mt. Bourgeau
Mt. Ball
Sulphur Mtn.
Indian Peak
MOUNT ASSINIBOINE
Mt. Mercer
Mt. Eon
Mt. Harkin
Mt. Byng
Mt. Birdwood
Mt. Sir Douglas
Mt. Queen Mary
Mt. King George
Bugaboo
Spillimacheen
Bobbie Burns
COLUMBIA
MITCHELL RANGE
KOOTENAY
Radium Hot Springs
Fairmont Hot Springs
Invermere
Columbia Lake
Palliser River

Company, was undoubtedly the first white man to cross the Rockies south of Peace River. In June 1807, he left the Northwesters' post at Rocky Mountain House, went over Howse Pass and down Blaeberry River to the Columbia and established Kootanae House on the west bank, near the present village of Wilmer. A monument now marks the site of this important outpost. As far as is known this was the first trading post within the entire Columbia River system. An interesting, but probably not very authentic, replica of this post and surrounding stockade and bastions has been erected at nearby Invermere on Windermere Lake as a community centre. From his Kootanae House Thompson commenced his seven years of exploration west of the Rockies, charting the Columbia from its headwaters to the sea[1] and developing firm trading relations with the Indians of the Columbia and Kootenay valleys.

Three minor items are of interest respecting Thompson's sojourn on the Columbia. He included in one of his fur shipments to England a number of Rocky Mountain goat skins, despite much ridicule from wintering partners in the fur trade. The pelts proved to be novelties in London and brought excellent prices. Despite repeated requests, Thompson steadfastly refused to send more goat skins because of the earlier local criticism. In the Trench valley, Thompson encountered many herds of wild horses. Their history remains a mystery. They may have been strays from Indian encampments, but it is possible that they descended directly from Spanish stock during their occupation of the southwestern States. Thompson made two attempts to obtain a satisfactory barometer from England for altitude determinations. Through the carelessness of those entrusted with bringing the instruments from London, they arrived too badly broken to be used. Hence, all Thompson's elevations in the mountainous areas quoted in his journal, were determined by observing the temperature of boiling water.

Until 1812, Thompson made several extended trips across the mountains either by Howse or Athabaska Pass. He discovered this latter pass in 1811 when hostile Peigan Indians blocked his eastward passage through Howse Pass.[2] The Athabaska Pass became the "main line" of the fur brigades and Howse Pass fell into disuse. The southern Alberta passes were not used prior to the 1860's because of the warlike character of the Blackfoot Indians in southern Alberta.

THE ITINERANTS

In 1821 the Northwest Company merged with the Hudson's Bay Company. The first territorial governor of the Company, Sir George Simpson, was a tireless world traveller, and had a great desire to see at first hand the conditions of the fur trade. He first crossed the Rockies via Howse Pass in 1824, and again in 1829. In August 1841, on a trip around the world, he ascended Bow Valley to Healey Creek, about five miles west of the present town of Banff, crossed the divide by what is now called Simpson Pass and proceeded down Vermilion River and over Sinclair Pass to the Columbia. In his narrative of the journey, Simpson vividly describes Sinclair Canyon and the Hot Springs at Radium. He mentions a party of emigrants comprising some 23 families, led by James Sinclair, which left Red River Settlement in Manitoba, headed for the rich farm and ranch lands at Fort Coville in northern Washington. The party followed Simpson's trail as far as Bow Valley where their guide deserted. Left to their own devices, they engaged an Indian guide, Bras Croche, who took them over a pass to the south of Simpson's Pass. This pass was undoubtedly the present Whiteman's Pass. The great western traveller Father de Smet, of the Oregon Missions, traversed the same pass in 1845. The cross planted by de Smet at the summit was well known to the Indians. The name of Cross River, draining into the Kootenay, commemorates this incident.

On the Whiteman Pass, de Smet met a very interesting party travelling westward. To all intents and purposes, it was a company of English gentlemen in leisurely tour of the country.

[1] It is a remarkable tribute to Thompson's cartography that, until 1927, his great map was the only accurate portrayal in existence of the Columbia drainage system.

[2] This pass was named by the Hudson's Bay Company for one of its factors, Joseph Howse, despite the fact that he did not cross it until 1809, two years after David Thompson.

Actually, the principals of the group, Lieutenant Harry Warre and Lieutenant M. Vavasour of the Royal Engineers, were acting as secret agents on a highly confidential assignment for the British Government. It is now known that the purpose of their trip across the mountains and on to the Pacific Coast was to gain accurate military information regarding the requirements for the possible defence of the Washington, southern British Columbia area in case of attack, either by the United States or Russia. The feasibility of moving troops through the mountains and the minimum requirements for the defense of strategic points along the Columbia and on the coast were within the scope of their enquiry. The following year (1846) these men returned by the Athabaska Pass. It has been suggested that Father de Smet had made his trips into Canadian territory to gain equally desirable information for the United States government.

LATER EXPLORATIONS

These brief comments have attempted to bridge the period from the discovery of the Columbia-Vermilion area in 1858 through citation of its earliest incidental visitors. The period that follows, from 1858 to the present, has seen a large number of formally organized explorations, with widely different objectives, enter the region. It is not within the scope of this resume to discuss the results of these surveys. Rather it seems more in keeping with our theme to attempt a brief analysis of the historical background which prompted them.

From 1670 until 1870, the Hudson's Bay Company held exclusive trading rights over a territory that included most of Canada west of Hudson Bay. This concession carried the obligation that the Company conduct exploration and encourage settlement in the arable lands of the West. When, after 180 years of operation, the Company could point to very little exploration, and still less settlement, the Imperial Government professed a desire to obtain independent information regarding the economic worth of the country. An expedition was assembled in 1856 under Capt. John Palliser with Dr. James (later Sir James) Hector as geologist. One of the directives to the Palliser Expedition was "to ascertain whether one or more practical passes exist over the Rocky Mountains within British Territory." In the course of examination of the known passes, Hector, in 1858, came down the Columbia from the Kootenay and up Kicking Horse River (so named after an incident wherein Hector was kicked by one of his pack horses). These travels in search of passes permitted Hector to amass the first geological data concerning the Rockies, particularly in regard to the major rock systems represented and the general structural alignment of the mountains. Perhaps the most important contribution by Palliser and Hector was a much more detailed map of the region than had previously existed. The names of hundreds of creeks, rivers, and mountains were selected by the expedition and appear on their maps. These explorations were of considerable importance in directing the early location surveys for the Canadian Pacific Railway, despite the fact that the Palliser Expedition did not recommend any passes observed as satisfactory travel ways.

Gold had been discovered in California in 1849, and as the excitement died down, miners drifted to other areas. Some went to the Barkerville country of central British Columbia to participate in the Caribou Gold Rush. Others commenced panning the creeks tributary to the Kootenay. Excellent values were found on Wildhorse Creek in 1864 east of Cranbrook, near the south end of the Trench, and by 1885, over half a million dollars had been taken out of the gravels. After the virtual exhaustion of the workings in the '70's, mining activity in the region languished until after the coming of the railroad. It is of interest that many hundreds of Chinese men participated in the Wildhorse strike. The Chinese graveyards near Fort Steele are interesting records of those days.

THE COMING OF THE RAILROAD

The Crown colony of British Columbia agreed to join Confederation and become a part of Canada by 1871, provided that a transcontinental railroad would, within 10 years, reach from

Eastern Canada to the Pacific. The magnitude of this undertaking is difficult to appreciate in our age when 2,000 mile pipelines are no novelty. The financing, surveying, and construction, particularly through the Rockies, presented a formidable task. Under the general supervision of Sanford Fleming, Chief Engineer for the construction, concentrated surveys of the Rockies commenced in 1871, to find a suitable pass. Walter Moberley, a reconnaisance engineer from British Columbia of great energy and tenacity of purpose, explored summer and winter, all known passes. The record of his exploits is one of gruelling hardship in the high Rockies during the depths of winter. His first choice was the Howse Pass, but others favored the lower, more northerly Yellowhead Pass.

The newly built Northern Pacific Railroad was busily engaged in running feeder lines northward into the southern part of western Canada. The Canadian Government feared that if it did not attempt to serve these areas, it would be only a matter of time before the United States would exercise practical sovereignty over an important part of the west. Reluctantly, plans were changed and the Yellowhead Pass idea was abandoned for the more southerly, but much more difficult, Kicking Horse Pass. It was 1875 before plans and, particularly, financing of the railway project was sufficiently advanced to permit the commencement of construction. The first sod of the Canadian Pacific Railway was turned on June 1st, 1875, on the Kamanistaqui River in Ontario. The British Columbia Government had to be persuaded to grant a four year extension of time. Once started, events moved rapidly. The line had advanced as far as Winnipeg by December 31st, 1882. The first train reached the village of Calgary by August 1883, and track was complete to Laggan at the summit of Kicking Horse Pass by year's end. Much the greatest task was the building of the mountain section through the Selkirks and the Rockies.

This formidable task was tackled from both ends. Under the able leadership of the Government contractor, Andrew Onderdonk, a gang of over 7000 men pushed the tracks eastward from Vancouver, to the heart of the Selkirks. These men were a weird assortment—Chinese brought over from the Orient against strong local opposition, the riff-raff of the waterfronts of the west coast, and graduates of San Quentin. Regardless of their background, they really worked—pushing the right-of-way up gorges and across rivers under some of the most difficult conditions ever encountered in railroading. Equally active was the eastern gang of Swedes, Norwegians, and Finns pushing westward over the Kicking Horse summit and into the Selkirks under the driving leadership of Major A. B. Rogers and Herbert (later Sir Herbert) Holt. On November 7th, 1885, the two parties met at Craegellachie in the Selkirks, about 120 miles west of Golden, and Lord Strathcona drove the last spike[1] to complete the first Canadian transcontinental railroad.

It might be assumed that the rapid construction was on "a get there at any cost" basis, with temporary bridge structures and sub-standard grades. This was definitely not the case. The engineering and construction was of the highest order and the whole enterprise is justly included among the world's great engineering projects. The leaders of the Mountain Division construction were truly men of stature. Andrew Onderdonk, upon completion of the Canadian Pacific Railway, built railroads in South America and superintended the digging of the East River Tunnel in New York City as well as other projects. Herbert Holt, contractor on the Kicking Horse section, worked his men with an iron hand and terrific drive. In later years he became a well known financier and one of Canada's wealthiest men.

Law and order along the line of construction was maintained by the Northwest Mounted Police. In general, there was little trouble. On one occasion, after the pay for the workers was long delayed at Beavermouth, a trouble-making element among them incited the men to strike and commit acts of violence. Colonel Steele, in charge of the small detachment, together

[1] It is of interest to note that a gold spike was made for the occasion but was not used because of the fear that souvenier hunters might dislodge the tracks in attempts to purloin it.

with Sergeant Fury, held the strikers at bay at gunpoint while George Hope Johnson, the local justice of the peace read the Riot Act. After the Colonel threatened to take whatever measures the law permitted, the men dispersed.

Of all who worked on the Rocky Mountain-Selkirk section much the most colorful was Major Rogers, a short, snappy, little New Englander, graduate in engineering from Yale, and a wizard at cutting construction costs. John Lane in "Canada's Great Highway" makes these observations of Rogers' gentility, "He was a master of picturesque profanity, who continually chewed tobacco and was an artist in expectoration. He wore overalls with pockets behind and had a plug of tobacco in one pocket, and a sea-biscuit in the other, which was his idea of a season's provisions for an engineer. His scientific equipment consisted of a compass and an aneroid slung around his neck."

If it were not for such men on the job, the first train over the new road might well have been years late.

The Big Hill between Field and Kicking Horse Summit early proved a great bottleneck to economic operation in the mountains. At times, as many as five locomotives were needed to push trains over the "Hump." In 1908 the construction of the spiral tunnels east of Field was commenced. Their completion permitted a complete loop inside Mount Burgess and another in Cathedral Mountain, lowering the grade appreciably. One thousand men worked two years removing 750,000 cubic yards of rock to accomplish this remarkable feat of engineering.

Among the interesting aspects of the early railroad construction in the mountains, was the first use in Canada of photo-topography as an aid in making accurate maps of right-of-way. This system, perfected by Dr. Deville, then Surveyor General of Canada, was the greatest advance in topographic mapping that had been made before the advent of aerial photography.

ADVENT OF THE ROCK HOUNDS

The Geological Survey of Canada, regarded as the senior exploring organization of the Dominion, was recruited to do whatever possible to aid in the appraisal of the lands adjoining the railroad. Even before the completion of the C.P.R., parties were rushed west to look for coal deposits and determine the fertility of the lands across the prairies. Foremost among these western investigators for the Survey were Dr. George M. Dawson and R. G. McConnell. After exploring the Alberta plains between 1881 and 1882, Dawson constructed the first regional geological map of the Rockies in 1885. His traverses covered a vast territory from Kicking Horse Pass south to the United States Boundary. While he outlined many important coal basins, one of his most interesting observations was the finding of a unique intrusive of blue sodalite syenite on Ice River, 14 miles south of Field. This and a few small nearby intrusives are among the few known igneous rocks in the entire Rocky Mountains. The petrology of this interesting alkalic intrusive which runs the gamut of differentiation products from nephylene syenite to the ultra-basic jacupirangite was worked in detail by J. A. Allan from 1911 to 1914, in his study of the Field map area. The intrusive stands like a sapphire set on the face of the keystone. In 1885, McConnell commenced the measurement of exposed rock sections across the Rockies and gave the first comprehensive stratigraphic and structural section of the region. Of particular interest was the discovery by Mr. L. M. Lambe, then one of the surveyors on the railroad construction, of Cambrian trilobites at Field. Lambe later became Assistant Palaeontologist for the Geological Survey of Canada. Both Dawson and McConnell made extensive Cambrian collections, parts of which were forwarded to Dr. C. D. Walcott of the Smithsonian Institution, then the leading authority on Cambrian faunas in America. So impressed was Walcott with the perfection of the fossil material, that he came to Field in 1907, and from then until 1928 came many times to continue his studies of the fossil faunas. While his stratigraphy

sometimes reflects the inability of a man in his sixties to determine from the valley floors the details of the strata on the mountain tops, his palaeontology is regarded as excellent.

All geological students take at least one course of palaeontology and memorize long lists of fossils, which they promptly forget. A little "Gallup" poll conducted by the writer over the years indicates that if all other names are forgotten, one fossil name *Ogygopsis klotzi* Roeminger is retained. Such latent palaeontologists will be interested to know that Otto Klotz, while doing astronomical work for the Dominion Geodetic Survey, accidentally discovered the famous Mt. Stephen fossil bed and presented his collection to his Alma Mater, the University of Michigan. Eventually it found its way to Dr. C. Roeminger, who, in 1882, described them in the National Academy of Science Proceedings. The original name of the form was *Ogygia klotzi,* but Dr. G. F. Matthew, the New Brunswick customs official who became the great student of the Atlantic Cambrian faunas, proposed the present name.

The perfection of the Cambrian forms found in the Kicking Horse area had a marked effect on prevailing theories of evolution. These faunas demonstrated beyond doubt that organic evolution was much further advanced in Cambrian time than had hitherto been thought.

Of the later surveys of the area, one of the most interesting is that of J. N. Wallace, A. O. Wheeler and A. W. Cautley, representing respectively the Dominion, British Columbia, and Alberta, in the fixing on the ground the Alberta-British Columbia boundary south of Latitude 52°30′. Here the boundary is defined as the Pacific-Atlantic watershed. The following of such a boundary necessitated one of the most arduous climbing assignments ever concocted. More recently, detailed geological surveys by Schofield (1914 to 1923), Shephard (1922), Walker (1926), and Evans (1933), have unravelled much of the complicated structural and stratigraphic detail of parts of the Keystone region. Of particular interest was the recognition of rocks of Silurian age in the Brisco-Beaverfoot Range, and the associated black Ordovician shales with a graptolite fauna closely correlative with the Normanskill fauna of New York State. That the structure along the Rocky Mountain Trench is complex, no informed observer will deny. The Trench itself, traceable as a fairly continuous topographic feature from northern Montana to the Yukon, is among the larger physiographic features on the earth's surface. It has been studied by many geologists at widely separated localities, and each has invoked a different theory for its origin, as discussed elsewhere in this guidebook. Without in the slightest degree belittling the efforts of these observers, one is reminded in retrospect of the old poem regarding the six blind men of Hindustan studying the elephant. Each feeling a different part of its anatomy arrived at an independent concept of its probable nature. It is likely that when the whole story is known, the Trench will be found to have a most complex geological history attributable to different sets of forces acting at different times in different areas.

In 1911, Canada was host to the International Geological Congress, which toured from Montreal westward to the Pacific Coast along the C.P.R., and returned along the present route of the Canadian National. The distinguished visitors were entranced with the perfection of geological exposures along the route through the Rockies and many returned at later times and contributed papers on items of their interest.

MINES AND OTHER MATTERS

Mention has been made of the general lack of igneous rock in the sedimentary section comprising the Rockies. On these grounds one might regard the Keystone area as having a low degree of prospectiveness for metallic mineral deposits. Yet in a narrow belt trending more or less normal to the mountain strike, and including the Keystone area, small deposits of copper, lead and zinc have been found. One of the most interesting, if not the most lucrative, was an occurrence of chalcopyrite on Copper Mountain, 15 miles west of Banff. Claims were taken in

PLATE 1

Silver City, at the base of Mount Eisenhower (Castle Mountain), about 1880. Some silver was mined on Castle Mountain, the workings lying behind the southeast shoulder, visible in the background. The camp was established by prospectors enroute to the Cariboo country. By 1900 only one building remained. Photograph from the collection of H. Pollard Sr., Calgary, Alberta.

PLATE 2

Highway between Field and Golden on the day it was opened to the public in 1927. The photographer's car, shown in the picture, was the first through. Photograph by H. Pollard Sr., Calgary, Alberta.

PLATE 3

Representation of Kootenae House, near original site at Invermere, B.C. The more recent structure was built as a community centre about 1922 Photograph courtesy of Hal Bavin, Windermere, B.C.

PLATE 4

Monument on the permanent site of Kootenae House, a short distance from the first, at Wilmer, B.C. Photograph courtesy of Hal Bavin, Windermere, B.C.

the name of the Alberta Mining Company in 1885, and a small rush ensued. Like other such occurrences, these showings had negligible gold values and proved uneconomic.

As railroad construction passed through Field, showings of lead and zinc ores were found well up on both sides of the canyon walls. Despite the real hazards of operation on almost vertical cliff faces, hundreds of feet above the valley floor, scores of tunnels have been driven. The Monarch mine has been the most actively worked, passing over the years through several hands. During and after World War II, this mine was very active. The ore was lowered from the cliff face by aerial tram to a concentrator in the valley.

Unrelated in genesis, but of very considerable economic importance, is an extensive occurrence of gypsum in the Devonian rocks of the Brisco Range. These deposits are traceable on the surface by a series of sink holes, some of which measure 75 feet in depth and diameter. The gypsum is being actively worked at present and is finding a ready market in the State of Washington and in cement plants near Calgary.

The hot springs just west of Banff were known to the Indians but were first recognized by white men during the construction of the Canadian Pacific Railway in 1882. It was decided to set aside ten square miles as a National Park "dedicated to the people of Canada for their benefit, education and enjoyment." In 1887, the area was greatly expanded to 29,000 square miles. Yoho National Park, an area of 507 square miles, straddles the railroad in the environs of Field. It was founded just after Banff Park, in 1886. It is of interest that the word "Yoho" is an Indian word meaning "It is Wonderful." With the development of a road across Vermilion Pass on to Radium, over Sinclair Pass, the Kootenay National Park was created in 1920 with an area of 543 square miles. In addition to being national playgrounds, these parks are wild animal sanctuaries. As such, they have played a very important part in saving many of the most interesting mountain animals from extinction.

The Canadian Pacific Railway early attempted to develop Field as a tourist centre. As big game hunting languished in the area, the focal point of the company effort was changed to Banff upon completion of the Banff Springs Hotel.

THE RESIDENTS

The reader will undoubtedly have been surprised that our brief history of this region has discussed the exploits of many travellers but has said virtually nothing regarding the residents. Much of the area is too rugged to encourage permanent residents other than the few who care for the wants of the tourist. In the broad open valley of the Trench around Windermere and Columbia Lakes, the warm climate and prospects of agricultural development encouraged many settlers. Early in the present century, one resident of the valley, R. Randolph Bruce, who later became Lieutenant Governor of British Columbia, encouraged the brokerage firm of Beiseker and Davidson from North Dakota and Mr. J. S. Dennis of the Canadian Pacific Railway to join with him in the formation of the Canadian Pacific Irrigation and Colonization Company. A million dollar interest bond issue was floated. The objective of the company was to draw water from the creeks, irrigate the benches, and develop fruit farming. Many English emigrants were brought over but most proved unadapted to the country, and the climate unsuitable to orchards. In short, the fruit venture proved fruitless. Agriculture has made little headway in recent years. The reputed curative properties of the hot springs attracted some in need of treatment. The Fairmont Spring was once held within a ranch operated by Sam Brewer, brother of D. J. Brewer who served from 1899 to 1910 as one of the Justices of the United States Supreme Court. The springs at Radium were once the property of one, Eric Harmsworth, brother of Lord Northcliffe, the well known English publisher. These springs have since reverted to the Dominion Government, and it has greatly developed them, providing excellent public bathing facilities.

An attempt was made to develop continuous navigation service between the Kootenay and the Columbia as fulfillment of a requirement of the land grant. A canal was actually dug at Canal Flats and in compliance with the terms of the concession, a boat was actually forced, more by brute force than motive power, through the canal. The scheme proved impractical and the contact with the world continued to be made through the medium of the Canadian Pacific Railway branch line joining the Crowsnest line and the main line at Golden.

It would be remarkable if such a region as that described did not raise its full share of "characters." Their history is recorded in the minds of the residents, rather than in our libraries. Time has not permitted the writer to track down those who could best tell their story.

For one hundred and fifty years, this lovely land has incited the interest and curiosity of thousands of people from all walks of life and from all continents. The writer, during many visits, has grown to expect the unexpected. Once he just missed by hours the only successful elephant hunt ever organized in British Columbia. A circus train turned over near Cranbrook, permitting the massive beasts to take to the woods. Interest was aroused a few years ago by reports from forest rangers that a volcano had erupted in the mountains east of the Trench. The volcano proved to be nothing more than mud slides. Who can tell, next week a submarine may surface in Radium pool or oil may be struck in the Precambrian of the eastern Selkirks.

REFERENCES

Allan, J. A.: Field Map Area; Geol. Surv., Canada, Mem. 55 (1914).

Daly, R. A.: North American Cordillera at the 49th Parallel; Geol. Surv., Canada, Mem. 38 (3 vols.) (1912).

Dawson, G. M.: Preliminary Report — that portion of the Rocky Mountains, etc.; Canada, Geol. & Nat. Hist. Surv., Ann. Rept. (1886).

Evans, C. S.: Brisco-Dogtooth Map-area, British Columbia; Geol. Surv., Canada, Sum. Rept. (1932, Pt. A II).

Gibbon, John Murray: The Romantic History of the Canadian Pacific; Tudor Publishing Co., New York, (1937).

Macbeth, R. G.: The Romance of the Canadian Pacific Railway; The Ryerson Press, Toronto. (1924).

Mackenzie, Alexander: Voyages from Montreal on the River St. Lawrence Through the Continent of North America to the Frozen and Pacific Ocean &c; London 1801, (John Garvin Edition, Toronto 1927).

McConnell, R. G.: Report on the Geological Structure of a Portion of the Rocky Mountains; Canada, Geol. & Nat. Hist. Surv., Ann. Rept. (1886).

Tyrrell, J. B.: David Thompson's Narrative of his Exploration in Western America; Champlain Soc. (1916).

Walcott, C. D.: Series of Papers; Smithsonian Misc. Coll., Washington (1908-1928).

Wallace, J. N.: The Passes of the Rocky Mountains along the Alberta Boundary; Hist. Soc., Calgary, (April 1927).

Woodward, Henry: A Collection of Middle Cambrian Fossils Obtained by Edward Whymper, Esq., F.R.G.S., from Mount Stephen, British Columbia; Ex. Geological Magazine, Decade IV, Vol. IX, pp. 502-505 & 529-544, (November and December 1902).

Report of the Commission Appointed to Delimit the Boundary between the Provinces of Alberta and British Columbia: Pt. I-1913 to 1916; Pt. II-1917 to 1921; Pt. III-1918 to 1924; Office of the Surveyor General, Ottawa.

Journals, detailed Reports and Observations Relative to the Exploration by Captain Palliser, etc.; London, Govt. (1863).

SUMMARY OF THE GEOLOGY OF THE SOUTHERN ROCKY MOUNTAINS OF CANADA

A REVIEW OF THE STRUCTURE AND THE PALAEOZOIC STRATIGRAPHY OF THE CANADIAN ROCKY MOUNTAINS BETWEEN LATITUDES 49° 30′ AND 52° 30′

F. K. NORTH AND G. G. L. HENDERSON[1]

INTRODUCTION

The Rocky Mountains offer the most spectacular succession of sedimentary rocks to be found at the surface anywhere in Canada. Structurally, faunally, and scenically they are equally satisfying. From the standpoint of exploration geology, the bases of their structure and stratigraphy were laid as long ago as 1886, by R. G. McConnell. This date was only two years after that of the publication of the first German edition of "The Face of the Earth;" two years, also, after the original publication of the results of Peach's and Horne's work on the northwest Highlands of Scotland. The whole stratigraphic subdivision of modern Canadian Rocky Mountain usage was established before the first world war.

It is strange that so little progress has been made since. Whilst oil companies and the Geological Survey of Canada have explored the Foothills and parts of the Front Ranges, practically nothing new has been published on the Main Range beyond some stratigraphic and faunal detail for the easily accessible pass sections. Whole tracts along both sides of the Continental Divide remain unmapped geologically and virtually without reference in the literature. The geologist in the Canadian Rockies is thus poorly provided with geological maps and reliable field data, particularly by comparison with his colleague in the Appalachians or the Alps. The most recent full survey of Canadian geology to be published contains almost 350 pages of data. Of these, five and a half pages are devoted to the Palaeozoic stratigraphy of the whole eastern Cordillera. The structure of the Rocky Mountains, including that of the far northern ranges, is covered in 27 lines and one cross-section, about one quarter of the space devoted to the structural geology of the Plains.

This paper is an attempt to provide, for the field geologist, a summary of our present understanding of the geology of the southern Rocky Mountains. It will soon become apparent that both the data presented, and the interpretations offered, are in some cases rather strongly at variance with those in previous publications. The whys and wherefores of individual departures from tradition will be explained in the text, but some preliminary comment of a general nature is perhaps called for.

Practical geology, as an empirical inexact science, depends upon observation first and interpretation afterwards. It is the primary task of interpretation to attempt to account for all that is observed. In geology it is never possible to do this completely, and seldom even adequately, but this does not absolve the geologist from being aware, and in publication from making his readers aware, of the observations needing explanation beyond what he is able to offer. The Canadian Rocky Mountains have been perfunctorily treated in this regard. Many well known and easily observed features of Rocky Mountain geology remain unmentioned in the literature, or have been mentioned without any attempt at explanation.

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Almost one hundred years ago, James Hall published the first statement of his theory that mountains are merely thick accumulations of sediment; that their existence as mountains, in fact, stems entirely from this characteristic. J. D. Dana described this as "a theory for the origin of mountains, with the origin of mountains left out." This would be a fair comment on much of the previously published structural data for the Main Range of the Canadian Rockies; the structure has been made to appear so simple that there is no apparent reason why the mountains exist. The stratigraphy, on the other hand, still rests largely on the foundations erected by Walcott, and in this form it is so unbelievably complex that it defies analysis.

Experience shows that, in mountain ranges composed of sedimentary rocks, the stratigraphy before deformation must have been relatively simple. The complication is in the structure. There is no need to attempt to reverse this experience for the Canadian Rockies. Structure sections showing them to be a dissected high plateau, with poorly developed basin and range structure, cannot adequately represent them. The stratigraphy can be reduced within the limits of comprehension without invoking Walcott's five separate geosynclines. The chief departures from traditional views in this paper, therefore, will be a great simplification of the stratigraphy and an interpretation of the structure involving much greater complexities.

The publication of this guidebook provides an opportunity to draw attention to the geological problems of the mountains which must be answered and to which no adequate answers have been offered. We will adopt the 'Irish' approach, and give the evidence first, with our interpretations of it. The questions which these interpretations are meant to answer can then be posed afterwards. It is scarcely necessary to add that the interpretations consist largely of hopeful guesswork; they are offered here as possible points of departure for the more thorough and comprehensive study which the Canadian Rockies certainly need and certainly deserve.

The subject is a very large one and offers scope for a fine variety of opinions. For obvious reasons, however, this paper has had to be kept within reasonable limits of length and to be prepared in a very short time. In the interests of speed and clarity, therefore, we have set down our opinions as dogmatic statements. Most geologists are able, we think, to distinguish between geological statements susceptible of proof and those beyond it. We ask the reader's patience with the very great number of flat pronouncements, in the paper, which come into the second category. The method will, we hope, prove less irritating than would the constant reiteration of that tiresome prefatory phrase, "in the opinion of the authors."

MAJOR STRUCTURAL SUBDIVISIONS

The Rocky Mountain system, as now commonly defined and as understood in this paper, is a geological and physiographical province distinctly separated from its neighbours—the Plains to the east, and the Interior or Columbia Mountain systems of British Columbia to the west. The province is readily divisible into a number of well marked sub-provinces, extending approximately parallel to one another in a general way. However, since the sub-provinces are structurally distinct, and in some cases structurally out of harmony with one another, they lose parallelism in places. As a result, not all sub-provinces are present at all latitudes. The only sub-provinces in common between the Crowsnest section and that through the Yellowhead Pass, for instance, are those of the Foothills and the Front Ranges. There is no Main Range in the Crowsnest section, and there are no Western Ranges in Jasper Park.

The most valuable feature of the Kicking Horse and Vermilion Pass sections, through which this field trip will be taken, is that they include the maximum possible number of sub-provinces of the Rocky Mountain system. At this latitude, these are as follows, from east to west:

1. Foothills Sub-province.
2. Front Ranges Sub-province.
3. Main Ranges Sub-province.
4. Western Ranges Sub-province.

These sub-provinces are separated from one another by major faults, or fault-zones, just as the whole Rocky Mountain province is separated by major faults or fault-zones from the geological provinces on either side of it. Each sub-province is characterized by particular features of topography, structure, and stratigraphy which are in contrast with those of its neighbours. Any experienced Rocky Mountain geologist should have little difficulty in identifying very quickly the sub-province in which he finds himself. (Plates 5, 6, 7, 8)

The Foothills sub-province is fairly well mapped and fairly adequately dealt with in the literature. It has also received a lot of attention from oil companies. This being so, it will not be dealt with at length in this contribution, and will be mentioned again only incidentally. The other sub-provinces, and the faults that separate them, will be dealt with more fully and individually, in the following sections.

The simplest way in which to picture the general structure is to consider each sub-province, and even each structural unit within a sub-province, as an individual wedge of strata underlain by its own fault—the fault usually marking its eastern margin. This fault, with the body of rock overlying it, plunges in a particular direction. The pitch of the fault and the plunge of the beds are not necessarily in complete harmony with one another, but no case is known to us of the beds plunging in one direction and their master fault in the other. The conspicuous disharmony is between *adjoining* structural units (usually sub-provinces as defined in this paper).

Most of the larger faults have been named, and those that have not will be named in this paper for ease of reference (Map No. 1). It should be stressed that, although these master faults can be represented on a map as extending for very long distances, individual fault planes are not always as persistent as they seem. At any one point along most of the faults, several actual fault planes may be found, one of the group being responsible for nearly all the throw at that place. Along the strike, however, the throw on this plane will commonly be found to decrease, possibly to zero, whilst that on one of the other planes will take over the greater part of the displacement. We do not know, for instance, that the Castle Mountain thrust, marking the front of the Main Range at Mount Eisenhower, has actually the same fault plane as the thrust underlying Pyramid Mountain at Jasper, or that below the Assiniboine block . Effectively, however, a single zone of thrust faulting marks all these three points, and in a work of this type it will be convenient to refer to this zone as if it were a single fault (as indeed it may be).

It has already been noted that the approximate parallelism of the major Rocky Mountain structures does not stand up to close scrutiny. The parallelism of individual ranges has been emphasized by the subsequent drainage pattern, a pattern clearly structurally controlled. However, the structures within individual ranges diverge in varying degress from this major control. A generalization, having perhaps the same order of validity as most generalizations in geology but not the less significant for that, is that both major and minor structures within the system, exclusive of the foothills, tend to be either over-ridden or truncated, at some point along their strike, by the next major structure to the west. In a mountain system combining strong folding and very powerful thrust faulting, over-riding of one structure by another is to be expected. Truncation may be a very different matter. Of several feasible explanations of it, one is that the system involves several major faults of transcurrent (strike-slip) type. The authors are satisfied of the existence of such faults among the controlling structures of the Canadian Rockies, and these will be described in some detail later in this paper.

In addition to the major longitudinal structures, there appear also to be some transverse structures of considerable magnitude. The largest of these are in the Hughes Range, these being

in some cases easterly extensions of faults lying essentially within the Purcell Range. In observed cases, the transverse faults are younger than the longitudinal faults, and offset them. The Bourgeau fault, however, and the other major faults of the Front Ranges sub-province, appear to be free of offset by transverse structures, so that there is here preliminary evidence of two periods of longitudinal faulting, the older in the west.

North of a line drawn about at right angles to the Rocky Mountain structures, and passing through Canal Flats, few transverse faults of any size have been mapped, and they appear to be much less common than in the Hughes Range. Some are known, however, and the general topographic grain suggests that there are others still unknown. The transverse upper reaches of the Vermilion River, from Vermilion Pass to Ochre Spring, appear to follow a transverse fault which has offset a major longitudinal fault laterally at least 7500 feet (see p. 31). The southwestward prolongation of this fault-trace passes through Wolverine Pass and across the faulted southern extremity of the exposed portion of the Ice River Complex. A further direct prolongation is in coincidence with the transverse fault across the northern end of Jubilee Mountain, a prominent rock ridge within the Rocky Mountain Trench. A similar continuation northeastward from Vermilion Pass crosses the abrupt southeastern end of Mount Eisenhower, around which the Castle Mountain thrust swings sharply to the west. Whether there is a single transverse fault along the length of this trend is not known, but at least four separate stretches of it are either known, or reasonably presumed,to be faulted in such a way that the northwestern side has been relatively offset to the northeast.

THE FRONT RANGES SUB-PROVINCE

This sub-province comprises for the most part a series of sub-parallel, west dipping thrust blocks, lying between the Foothills and the Main Range of the Rocky Mountains. The eastern margin, or front, of the sub-province is marked by a great fault, along which Palaeozoic beds of various ages (usually Cambrian or Devonian) have been thrust eastward over Mesozoic formations (usually Cretaceous). This fault was called the McConnell fault by Clark (1949, pp. 614, 631-2) in the Kananaskis area, where there is a superb exposure of Middle Cambrian limestone lying on the Upper Cretaceous.

Southward from the headwaters of the North Saskatchewan River, the Front Ranges are typically dominated by the great limestone formations of the Carboniferous and Upper Devonian. Each individual thrust-block, however, usually includes Mesozoic beds at the top (as in the type section of the Spray River formation, or the Cascade coal basin at Canmore), and may extend down to Cambrian formations at the base (as at Yamnuska Mountain and along much of the Sawback and Bourgeau Ranges). The typical dip of the thrust blocks over this stretch is between 30 and 45 degrees west (Plate 5); that of the Sawback block is usually considerably greater than this.

Northward from the North Saskatchewan River, the Front Ranges take on a rather different aspect, due partly, no doubt, to differences in the method of deformation, but also reflecting the much greater proportion of shales in the upper Palaeozoic succession. The individual ranges here are not simple thrust blocks, but show varieties of more intense folding, with considerably more of the overlying Mesozoics remaining in the inter-range belts.

The individual thrust faults within the sub-province are not quite parallel to one another, and so the number of "front ranges" is variable. South of the Athabaska River, there are four, from east to west called the Fiddle, the Miette, the Jacques, and the Colin Ranges. These ranges tend to lose their separate identity to the southeast, and on Brazeau River four are traceable only with difficulty. The front of the first is at Mount Dalhousie, of the second, at Mount

Isaac and Valley Head Mountain, of the third at Mounts Aztec and Olympus. The fourth is Le Grand Brazeau, a faulted anticline exposing a good deal of Cambrian rock. Thus the thrust fault separating the third and fourth ranges runs approximately along Maligne and Brazeau Lakes, and is here called the Brazeau fault. It is possibly continuous with the Bourgeau fault of the Bow River section.

South of the Saskatchewan River, the second of these ranges becomes the third, west of Whitegoat Cabin. The new second range is marked by a frontal fault which transects the headwaters of the north branch of Ram River, and crosses the Clearwater east of Peters Creek and the Red Deer immediately west of Tyrrell Creek. The third range fault of the Saskatchewan River section crosses the Clearwater west of Malloch Creek and the Red Deer at the mouth of McConnell Creek.

The Clearwater River is crossed by a fourth major fault, immediately below Martin Lake and less than two miles west of the frontal fault of the third range. This is the Bourgeau fault, and it is one of the greatest faults of the Rocky Mountain system. On the Clearwater, however, it can scarcely be said to mark a range of its own, but it crosses the peak of Mount Malloch, in the third range. On Red Deer River, however, there are four genuine Front Ranges. The McConnell fault (which southward almost to the Highwood River marks the front of the first range if inliers within the Foothills are disregarded) here passes through James Pass at the headwaters of James River. The first range, by this latitude, has taken on the composite form it exhibits farther south, in the Fairholme Range, and is about 15 miles wide at right angles to the strike. The second range of the Saskatchewan River section is continuous to south of the Red Deer River, where it is represented by the Bare Mountains, the northern extension of the Palliser Range. This second range is thus within the same thrust block as Mounts Girouard and Inglismaldie, south of Lake Minnewanka—mountains which are within the *first* range at their latitude.

The third range of the Saskatchewan and Clearwater River sections is represented on the Red Deer by Mount Prow, and its frontal fault is the Sulphur Mountain fault of Warren (1927, p. 43). It continues to mark the third range southward to Kananaskis Lakes, and in the Bow River section the Banff hot springs emanate from it.

The McConnell fault crosses Bow River at Kananaskis. After continuing southeastward in a sinuous course, past Nihahi Ridge and Mount Head, it loses its strongly folded and forward-riding upper portion and trends almost due south until it is cut off by the Lewis overthrust. South of the Highwood River, it also rapidly diminishes in its stratigraphic displacement, and thereafter has thrown Mesozoics against Mesozoics. In the Crowsnest Pass the fault does not bound a range at all, its trend following that of the rib of Kootenay coal-measures running north-south through Coleman.

The second range on Bow River is bounded to the east by the fault underlying Cascade Mountain and Mount Rundle—the Mount Rundle fault of Clark (1949, p. 630). This marks a new fault block not present on Red Deer River; it is abruptly wedged out northward at Cascade River. The Mount Rundle fault has no very great extension southward either, reaching only as far as the headwaters of the Elbow River. A much smaller member of the same fault zone separates the most easterly peak of the Three Sisters, at Canmore, from the central peak; at this point, this fault merely brings the lower Fairholme against the upper. However, continuing southward along the strike, across Kananaskis River and along the ridge of the Opal Mountains, this fault increases in throw and takes over the whole displacement of the Mount Rundle fault-zone. With a small lateral offset by a transverse fault on Pocaterra Creek, the fault immediately underlies the range forming the Continental Divide. Crowsnest Mountain is an outlier from it. South of Crowsnest Pass it flattens rapidly, and therefore swings abruptly eastward. It is, in fact, the Lewis overthrust, which underlies Waterton park and the whole of Glacier National Park in Montana.

At Kananaskis Lakes, the Sulphur Mountain fault (marking the third range for a very long distance northward) either dies out or is over-ridden from the west by the Bourgeau fault. Thus the fault-block containing Mount Norquay and Sulphur Mountain wedges out to the southeast; that containing Cascade Mountain and Mount Rundle wedges out to the northwest. At this latitude, therefore, the Spray Mountains form the third range, though they are the strike continuation of the fourth (Bourgeau) range twenty miles to the north. There are still four front ranges here, however, because a new one lies west of the Spray Mountains. This is the Royal Group. It comprises a tight faulted syncline which appears to plunge to the northwest, beneath the salient of the Main Range which forms the Assiniboine massif. The west flank of the Royal Group is also the west boundary of the Front Ranges sub-province at this latitude; it is bounded by the Stephen-Dennis fault. As will be explained later this fault marks the eastern front of the western sector of the Main Ranges sub-province (pp. 30, 31). On Palliser River, in other words, the *eastern* sector of the Main Ranges sub-province no longer exists.

The thrust fault below the east face of the Royal Group continues southward to cross the upper reaches of White River, west of Connor Lake. Beyond this point it has not been traced, but somewhere within the Elk River Game Reserve it must either die out or unite with the Bourgeau fault. It has already been observed that the McConnell fault zone rapidly decreases in displacement south of Highwood River, where it lies to the west of the Highwood Range. Another fault zone, lying three to four miles east of the McConnell fault, equally rapidly *increases* in throw southward. This is the Livingstone fault, a folded, low angle thrust fault, which to the north of Highwood River lies within the Foothills sub-province. At the latitude of the upper Highwood River, therefore, there are still four front ranges as there are in the Bow River section. The first, the Highwood Range, and the second, or High Rock Range, are both underlain by thrust faults which do not reach Bow River. The third, lying west of Elk River, is underlain by the same fault as the fourth (Sawback) range on Bow River. The fourth, west of White River, is underlain by a fault which may or may not reach Bow River; if it does, it is deeply buried below the Castle Mountain thrust.

In the general Crowsnest section, there are, technically, five front ranges. The new ones are the first, or Livingstone Range, and the fourth, which forms Erickson Ridge north of the railway loop. It should be observed here that *all* the front ranges, and their separating faults, plunge southward with only minor and local interruptions, from Bow River to Crowsnest Pass. Thus each front range, in general, exposes younger and younger beds from north to south, and a striking feature at the latitude of the Pass is the width of the intervening Mesozoic basins and the thickness of strata within them. The greatest of these, and a very old feature, is the Fernie Basin; the fifth range (that including Mount Hosmer) lies wholly to the west of it and only 12 miles from the Rocky Mountain Trench. There is thus some truth in the common comment that the mountains in the Crowsnest section look like the foothills of the more northerly sections. They are all front ranges, in the first place, and they have plunged south sufficiently far to involve much Mesozoic rock at the surface, and so to lose a good deal of elevation. It is also broadly true that the more easterly Front Ranges tend to resemble the Foothills in structure; the McConnell fault in particular is like many foothills faults in being in places much more continuously and more highly folded, and consequently much more sinuous in outline, than other Front Range faults. The most westerly of the Front Ranges, on the other hand, has some structural and stratigraphic features in common with the Main Range. As it is less well known than the other Front Ranges, and has not received the attention from oil companies that they have received, it deserves longer treatment here.

On the International Boundary, there are really only two front ranges. The first occupies Waterton and Glacier Parks and is wholly underlain by the Lewis overthrust. This fault marks the *third* range in the Crowsnest section, and the second on Highwood River, but the ranges in front of it in those sections are over-ridden by it southward. The second range on the 49th

PLATE 5

Looking southeast from south face of Mount Norquay showing typical Front Ranges. Dip slope of Mount Rundle on left, Sulphur Mountain in centre, and scarp face of Bourgeau Range on right. Photo by F. W. Beales.

PLATE 6

Lake Louise from the air, showing typical structure and stratigraphy in eastern sector of Main Ranges subprovince. To the approximate stratigraphic level of the top of the glacier, cliffs are composed of Lower Cambrian quartzites; upper cliffs are of Middle Cambrian limestones. Fairview Mountain rises above lake. Main peaks on skyline are Mounts Deltaform, Hungabee, and Lefroy. Photograph by G. G. L. Henderson.

PLATE 7

Looking south along upper reaches of Mitchell River. Shows eastern part of Mitchell Range, composed of beds of Goodsir Group overturned towards east and drag-folded. Stephen-Dennis fault to right of river. Lower slopes of Assiniboine massif on extreme left. Photograph by G. G. L. Henderson.

PLATE 8

View southward along crest of Brisco Range, typical of the Western Ranges structural sub-province. Note steep erratic dips, presence of only one feature-making horizon, and sharp bounding trenches on each side of sub-province. Wapta bend of Kicking Horse River on left; Rocky Mountain Trench on right.

Photograph by G. G. L. Henderson.

parallel is the Macdonald Range, lying west of the Flathead Valley and in the same longitudinal fault-block as the Fernie Basin. It includes, though it is not underlain by, the Bourgeau fault, which marks the fifth range at Fernie and the fourth on Bow River. The next range to the west, the Galton Range, belongs to the Western Ranges sub province.

There is thus a very pronounced change in the visible geology of the Rocky Mountains between the Crowsnest Pass and the International Boundary. On the latter there are not, in fact, any ranges typified by the sub-parallel structures of the Front Ranges farther north. The Macdonald Range includes a great deal of Mesozoic rock and is characterized more by folding than by faulting. The Lewis overthrust sheet is underlain by a warped fault of low dip, and cut by a number of subsidiary thrusts, also folded. Thus, although the first range here is a composite thrust-block in the same sense as is the first range on Bow River (underlain by the McConnell fault), the comparatively low dips of the faults, and their strongly-marked folding, destroy the parallelism which characterizes the Front Ranges farther north. Like most flat thrust faults of great horizontal displacement, the Lewis thrust tends to follow the base of a competent member for a considerable distance. Thus the fault at the surface, in Canada, is typically overlain by the Siyeh formation, and in Montana by the Altyn dolomite, which forms the whole block of Chief Mountain.

The general pattern of Front Ranges stratigraphy between the North Saskatchewan and Highwood Rivers, is very simple. The first range exposes the youngest beds, commonly of early Cretaceous age; the westernmost range exposes the oldest, commonly Cambrian and in many localities Middle Cambrian. Thus the youngest rocks in the sub-province, in general, occupy a belt between the first and second ranges—that is, they lie on the back slope of the first range. The oldest rocks, similarly, occupy a belt between the last front range (usually the equivalent of the Sawback Range) and the last-but-one—that is, they lie at the base of the scarp-face of the last range.

For some period between late Cambrian and earliest late Devonian time, the forward sector of the Front Ranges sub-province underwent mild erosion following slight upwarping. Some 2000 feet, or more, of late Cambrian strata were removed by this erosion, so that the first sediments of the Devonian transgression now lie, in the first range, on a bevelled Cambrian surface varying in stratigraphic elevation by at least 2000 feet. At Kananaskis, for instance, the Ghost River formation lies, without noticeable discordance, on the *Glyphaspis* zone of the Middle Cambrian. Between the Clearwater and North Saskatchewan Rivers, the beds below the time break in the same range belong in the *Dikelocephalus* zone of the Upper Cambrian. A true angular unconformity between the Devonian and the Cambrian is hard to find and may not exist, but the Cambrian surface is gently undulatory. No beds of Ordovician age are known in the first range, but they appear consistently in the Sawback Range, and probably also in the third range. Silurian beds are not known to be present anywhere in the sub-province.

The Sawback Fault Block

The Sawback fault block is a composite structural block. From the headwaters of the North Saskatchewan River to those of the Spray, it is the most westerly block within the Front Ranges sub-province. It is so called because it includes the Sawback Range, a prominent and striking member of the Front Ranges.

This composite block is bounded on the east by the Bourgeau fault (see L. M. Clark's sections accompanying the Society's 1950 Field Guidebook). On the west, it is bounded by a series of faults, the influence of each varying according to the latitude. Where the true Main Range is present, as in the Clearwater and Bow River sections, the western boundary of the

Sawback fault block lies at the Castle Mountain thrust, which has overridden the Sawback structures. From the cross-cutting headwaters of Spray River to some unknown point in the Elk River Game Reserve, there is a further front range fault block to the west of the Sawback block. Where there is no Main Range, as in the Crowsnest-Elko section and southward from it, the west boundary of the block is defined by a fault of the Western Ranges sub-province, or even by one which farther to the northwest lies in the Rocky Mountain Trench (see Map No. 1). In this latter case, however, the Sawback block does not contain any "Sawback structure."

"Sawback structure" is the structure typical of the Sawback Range in the narrow sense. Limestone beds with very steep westerly dip, in places upturned vertically, have been weathered into narrow, cockscomb ridges, beautifully exemplified in Mount Ishbel. The Sawback fault block is here described as "composite" because it includes more than one range of this typical "Sawback structure," as well as other ranges of much more gentle structure. These individual ranges within the block are commonly separated from one another by thrust-faults, just as the first range on Bow River embraces several individual thrust blocks.

The Bourgeau fault is the chief member of one of the greatest fault zones in the Rocky Mountain system. From the west boundary of the Macdonald Range, west of Flathead Valley, it underlies the Lizard Range and Mounts Proctor and Hosmer, west of the Fernie Basin, as a low-angle thrust. The fault trends northward along the west side of the Elk River valley, with steepening dip, and crosses Kananaskis Lakes; it is responsible for the longitudinal valleys of Smith-Dorrien and Smuts Creeks and the upper Spray River. It underlies the Bourgeau Range, and crosses Bow River at the horseshoe bend southwest of Mount Norquay. In the southern part of this course, upper Palaeozoic limestones have been moved over Lower Cretaceous and Jurassic; in Spray River valley, the beds above the thrust are Cambrian and those below it Triassic.

North of Bow River, the fault trends just west of north along the west sides of Fortymile and Sawback Creeks, past Mount McConnell, and crosses the Clearwater River at the falls below Martin Lake. It continues to the northwest at least as far as Saskatchewan River, and may be continuous with the Brazeau fault. For an unknown distance north of Bow River, a narrow wedge of the east limb of an anticline occurs in the hanging wall of the fault, the dip remaining nearly vertical. Thus the beds in the hanging wall, north of Bow River, vary in age from Devonian to Cambrian. Those in the foot wall are commonly Triassic or Pennsylvanian.

On the south slope of Mount Edith, a second thrust diverges westward from the main fault, and follows a rather straight course west of the Lookout Point to the west branch of Cascade River, immediately east of Block Mountain. It then appears to swing farther to the northwest, and to extend along the ridges west of Bonnet and St. Bride Glaciers, along Oyster Peak, and beneath Drummond Glacier. Beyond this area it has not been traced.

Each of these two thrusts marks the front of a belt of "Sawback structure." The wedge shaped inter-fault area is characterized by westerly dips, often steep, and by some thrust faulting, but it includes in addition an important massif of much less severe structure. This massif includes Bonnet Mountain and Mount Douglas, both capped by gently dipping Palliser beds, and intervening glacier-covered peaks.

South of Bow River, the composite block presents a rather different appearance, since the "Sawback structure" is restricted to a narrow belt at its *eastern* margin, forming the Bourgeau Range and the Spray Mountains. The steeply-dipping upper Palaeozoic beds on the west flank of the Bourgeau Range dip below the longitudinal valley of Brewster Creek, where they may be faulted but cannot be severely so, and come up again to a broad west limb which forms Pilot Mountain, Mount Bourgeau, and the peaks on the Continental Divide north of Mount Assiniboine. More or less steep dips continue to characterize the Sawback belt southward, but the real "Sawback structure" is more and more restricted to its eastern edge, and is finally truncated by the

frontal fault at Riverside Mountain, fourteen miles southeast of Upper Kananaskis Lake. In the Crowsnest section, there is no trace of it. The Bourgeau fault, there perhaps better called the Hosmer fault, has become an almost flat thrust making the western margin of the Fernie coal basin, and the range it defines looks just like the other front ranges.

Wherever the very steep Sawback structure is present, the Sawback block in general has suffered so much more extreme crustal shortening than the other Front Range fault blocks, that it seems likely that its structure at depth is more complex than it appears to be at the surface. There is some evidence that it may resemble the Main Ranges sub-province in being underlain by converging thrust-planes. As this evidence hinges on structures underlying the Castle Mountain thrust, it will be dealt with in the ensuing section.

THE MAIN RANGES SUB-PROVINCE

From Mount Assiniboine to Mount Robson, and beyond, there lies a belt of mountains differing in elevation, physiography, stratigraphy, and structure from the belt of the Front Ranges. It includes almost all the highest peaks of the Canadian Rockies, and most of the glaciers; from about Simpson Pass northward, it also almost continuously includes the Continental Divide. In addition to reaching the highest elevations, the belt also exposes the oldest rocks in the Rocky Mountains at these latitudes. The vertical stratigraphic displacement of the axis of the belt, against the Front Ranges, is of the order of two miles or more (compare, as a fair random example, stratigraphic elevations on Mount Ball and Pilot Mountain, almost facing one another across Pharoah Creek). The Front Ranges, in their turn, have been elevated more than three miles with respect to the Alberta syncline below them.

However, whereas the foothills are very severely disturbed, and the Front Ranges fairly severely so, the belt along the Continental Divide is, at the surface, relatively undisturbed. Immediately east of the belt of minimum disturbance, a belt of severe disturbance is met with (the Sawback Range); it is characterized by steep to vertical dip to the west. Likewise, another belt of severe disturbance (the Western Ranges sub-province) is entered immediately to the west of the gently undulating structures; in this western belt the structures are *overturned toward the west*.

The apparent movement of the central belt has therefore been upward and outward with respect to the belts on either side of it. The central belt itself is for the most part almost flat in structure (Plate 6); moreover, it is the only part of the whole system to contain a number of rather large *gravity* faults. The most logical explanation for these features is that the central belt is underlain by at least two major thrust-faults, converging downward. The wedge of rocks lying between these two major faults constitutes the Main Ranges sub-province of the Rocky Mountains, as defined here. Such a wedge has been reproduced experimentally by Link (1928, p. 830, Figures 9 and 10). The fault forming the eastern boundary, or front, we call the Castle Mountain thrust (Johnston Creek fault of Deiss, 1939, p. 962). That on the west we call the Chancellor fault; its trace at the surface lies close to that of the White River Break, but it must dip in the opposite direction and presumably it passes underneath the Break going southward. In the Bow River-Kicking Horse section, the panel contained by these great converging faults extend from Johnston Canyon to Leanchoil, approximately. In the Jasper section, it extends from just east of the town to the Rocky Mountain Trench. In the Crowsnest section, it does not exist.

At the latitude of Bow River, the sub-province is readily divisible into two sectors, eastern and western, so clearly defined that it will be convenient to treat them separately. The eastern sector, the true "Main Range," here includes the Slate Mountains, the Waputik and Bow Ranges, the Assiniboine massif, and other ranges not individually named. The western sector includes

the Ottertail and Mitchell Ranges. The division between the two sectors is marked by the Stephen-Dennis fault of Allan (1914, pp. 9, 67). The eastern sector plunges to the north, the western to the south, at this latitude. Hence the former widens, and the latter narrows, going northward. How far north the western sector extends before being pinched out, between the Stephen-Dennis fault and the Rocky Mountain Trench, is not known, but it probably does not reach the latitude of the Columbia Icefields. The eastern sector extends southward only as far as Albert River. Thus, north of the Icefields the whole Main Ranges sub-province is occupied by what is the eastern sector on Bow River; south of Albert River the whole sub-province is occupied by what is the western sector on Bow River. We do not mean to imply by this that no structural sub-division is possible in the Main Ranges sub-province at the latitude of Jasper. On the contrary, a very ready division is possible, but it is brought about by a major thrust-fault which resembles the Castle Mountain thrust, and which is not present in the Bow River section.

The Castle Mountain Thrust

This great fault defines the eastern boundary of the Main Ranges. In some places it appears to be a clean break, but in general it is probably more accurately to be described as a zone of thrusting. From near the bend of the Smoky River, east of Morkill Pass, it extends southeastward with a slightly sinuous trace past Pyramid Mountain at Jasper, along the east ridges of the Maligne Mountains, and up Poboktan Creek. It underlies the Mount Wilson-Mount Coleman syncline, follows along the west side of Siffleur River, over Pipestone Pass, and crosses Pipestone River by the warden's cabin. Visitors to the Skoki Ski Lodge stand immediately east of it. It passes between Ptarmigan and Baker Lakes and down the west side of Johnston Creek, swinging sharply to the west of the canyon. South of the highway, the trace of the fault runs almost due south across Copper Mountain and passes up the east side of Pharoah Creek, west of Simpson Pass, and below the west face of Simpson Ridge. It then swings eastward, below Lake Magog and around the Assiniboine massif, crossing the Continental Divide through Wonder and White Man Passes. It then swings west again and converges with the next fault to the west (the Stephen-Dennis fault), thus pinching out the eastern sector of the sub-province.

The dip of the thrust along its surface trace varies within only small limits. In general it is rather steeper below the pitch-depression, at the Columbia Icefield, and flattens gradually southward, though there are minor undulations clearly visible in several places. One such undulation must be responsible for the abrupt swing of the fault around the northern side of the Mount Assiniboine block. The average dip of the fault is between 30 and 40 degrees. In general the beds in the footwall dip more steeply than those in the hanging wall, as might be expected.

The beds overlying the front of the thrust are, in most cases, of early Cambrian age; those underlying it are commonly Devonian. North of Pipestone Pass, the footwall is in the Banff formation; in the Slate Mountains, the hanging wall is in the Precambrian Hector formation. The oldest beds known to form the immediate footwall, south of the Icefields, belong to the Ordovician part of the Goodsir group, which is over-ridden by the Lower Cambrian quartzites northeast of Mount Eisenhower. At Simpson Pass, the Lower Cambrian lies on the Devonian; still farther south, east of Mount Assiniboine, the Hector shales lie on the Devonian.

Where the overthrust block above the fault has been eroded back sufficiently far to remove the frontal syncline altogether (as between Mounts Eisenhower and Wedgewood), the main fault is seen to be underlain by at least one other large fault which it has over-ridden. This secondary fault can be traced down the west side of Mount Brett and east of Simpson Ridge. Northward and southward it appears to pass under the great salients of the main thrust. The beds caught between it and the thrust are tightly folded into an anticline, which forms Simpson Ridge. This really represents a fifth front range at this latitude. The beds east of the secondary

fault, however, forming the lower western slopes of the Pilot Mountain block, appear to be sharply overturned *towards the west.* Evans (1933, p. 162) considered that this implied an east dip to the subsidiary fault at depth. This seems to us extremely probable, and if it is the case it means that the Sawback-Pilot fault block resembles that of the Main Range sub-province in being underlain by converging thrust-planes. In contrast to the Main Ranges, however, this one suffered considerable lateral compression and relatively little vertical uplift. The Sawback block is so obviously different in structure from the ranges to the east of it that it is not likely that it is in any way a simple thrust-block. The hypothesis of a wedge fault block, over-ridden from the west by the frontal fault of a much larger wedge fault block, goes some way to accounting for the extreme crustal shortening that the Sawback block has suffered (see Section B-B[1]).

The Eastern Sector of the Main Ranges Sub-Province

In the Bow River-Kicking Horse Pass section, the eastern sector of the Main Ranges sub-province extends from Mount Eisenhower to Mount Stephen inclusive. On the Yellowhead Pass route, it extends from Jasper to the Rocky Mountain Trench. In the Crowsnest section it does not exist. Where present, it comprises a panel of almost flat-lying and highly competent Palaeozoic rocks, the dips on the flanks of the gentle, open folds in only a few cases reaching 25 degrees. Erosion in this thick panel has produced the high-shouldered, castellated peaks popularly thought of as typical "Rocky Mountains." They include all the famous peaks lying along the Continental Divide, as far south as Mount Assiniboine—peaks all looking more or less alike—Mounts Robson, Edith Cavell, Athabasca, and Saskatchewan; those around Lake Louise; Mount Temple, Storm Mountain, and Mount Ball.

The belt is marked by a wide frontal syncline, clearly visible between Mount Eisenhower and Helena Ridge as viewed from the highway east of Johnston Canyon. To the west of this syncline, an equally wide, open anticline exposes Precambrian sediments along the strike portion of Bow Valley. The Bow and Waputik Ranges lie along the west limb of this anticline, this limb differing from the east limb in being much broken by normal faults, all with very steep dips and all down-dropped to the west.

The whole wedge of the eastern sector plunges northward to a pitch depression underlying the Columbia Icefields. Thus, in the frontal syncline, a tiny remnant of late Cambrian Bosworth limestone is the youngest horizon remaining behind Mount Eisenhower, forming Stuart Knob which can be seen from the highway east of Johnston Canyon. Northward along the syncline, immediately east of the Banff-Jasper highway, the beds capping the mountains are progressively younger, until a fine section of the Upper Devonian forms the greater part of Mount Coleman, and Banff shales extend well down the peaks east of Sunwapta Pass. An even better illustration of the plunge is seen on the west limb of the main anticline, close to the Continental Divide. In the Bow Range, a small part of the lower Eldon (Middle Cambrian) caps Mount Temple, which has Precambrian beds at its base. About 50 miles to the northwest, a mountain of comparable height, Mount Forbes, has Mississippian limestones at the top and Upper Cambrian at river level. Hence the plunge along the strike, between Mounts Temple and Forbes, is some 8500 feet in 50 miles as measured on the top of the Stephen formation, or 170 feet per mile.

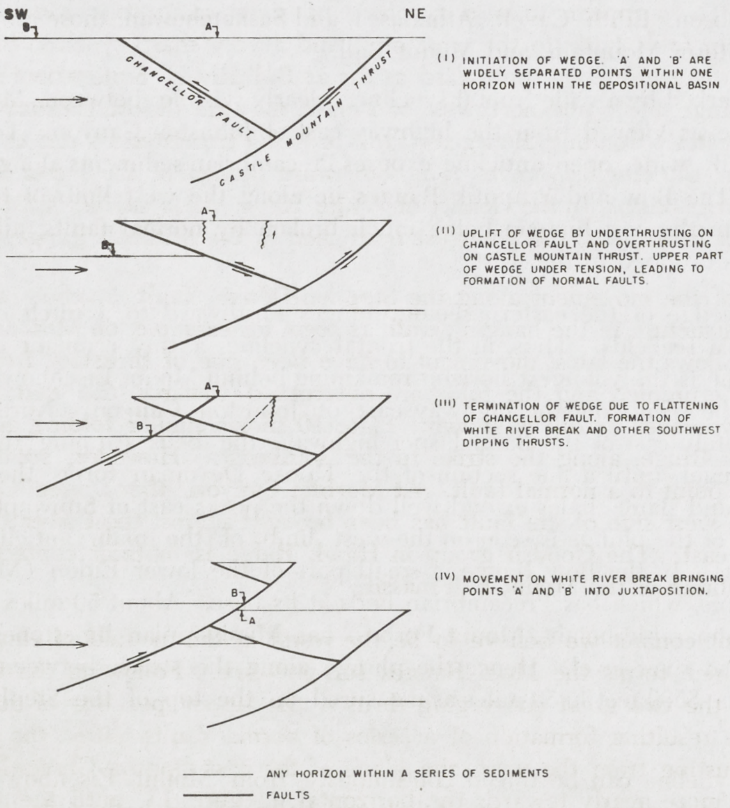
The frontal syncline can be traced continuously from Mount Eisenhower northwest for 130 miles to Mount Kerkeslin, opposite Athabasca Falls. From both ends it plunges towards the central pitch-depression at Sunwapta Pass.

Though the whole of this eastern sector of the Main Range is certainly underlain by the great Castle Mountain thrust, the sector itself, south of the Columbia Icefields, is cut by no

true thrusts, but entirely by faults originally normal. These we interpret as adjustment faults stepping down to the west, consequent upon the uplifting and eastward movement of the thrust panel. The throw of the normal faults is usually only a few hundreds of feet, except in the case of the Cathedral-Stephen fault, along which the throw is at least 3,000 feet. The plane of this fault is partly responsible for Yoho Valley, which it crosses with slight obliquity 2 and ¼ miles north of the "Meeting of the Waters". The block of the President Range is down-dropped to the west with respect to the Waputik Mountains. The fault crosses the eastern shoulder of Mount Field and passes between Cathedral Crags and Mount Stephen, throwing the Cathedral formation in the latter against the Lower Cambrian quartzites below the Crags. Thence it crosses Odaray Pass and extends down McArthur Creek, beyond which it is lost in the sheared zone along Ottertail Valley. The wedge between the Cathedral-Stephen and Stephen-Dennis faults is of interest palaeontologically, as both the Burgess shale and the *Ogygopsis* fossil-beds are known only in minor fault-blocks within it. (see p. 60).

The Western Sector of the Main Ranges sub-province

The boundary between the two sectors of the Main Ranges Sub-province, as here defined, is marked by the Stephen-Dennis fault, so named by Allan (1914, pp. 9, 67). The western



DIAGRAMMATIC CROSS SECTIONS SHOWING THEORETICAL
DEVELOPMENT OF WEDGE AND WHITE RIVER BREAK
FOLDING NOT SHOWN

Figure 1

sector differs markedly in stratigraphy from the eastern sector, but it is our opinion that the stratigraphic difference is basically one of facies, not of age (see pp. 48, 49). Structurally, the differences are twofold—the western sector is marked by a zone of intense shearing, unlike anything in the eastern sector; and the structures in the western sector plunge to the south, whereas those in the eastern sector, within the latitudes of this study, plunge to the north.

Hence the western sector narrows northward, in contrast to the northward widening of the true Main Range or eastern sector. How far north the western sector extends is not known, but it probably does not reach the latitude of the Columbia Icefields. There the eastern sector apparently occupies the entire width of the sub-province. The most northerly point to which the separating fault has been followed is Emerald Pass. Northward from the pass, it may lie along the west side of the President Range. Southward, its trace runs through Burgess Pass, between Mounts Field and Burgess, and thence between Mounts Stephen and Dennis, just west of the fossil beds. It crosses the west shoulders of Mount Odaray and Park Mountain, and at Marble Canyon lies between Mount Whymper and Prospector Mountain. South of Vermilion River the fault separates Stanley Peak from Vermilion Peak, and continues southward with steepening dip along Hawk Ridge and between Octopus Mountain and Indian Peak, northwest of Mount Assiniboine. At this latitude, the Assiniboine massif is all that remains of the eastern sector. Continuing southward, the fault plane coincides with the longitudinal section of Mitchell River and can be followed as far as Albert River, which it crosses east of Tangle Peak. A general fault-zone, probably including the Stephen-Dennis fault, may continue still farther south, along the west flank of the Royal Group of mountains, across Palliser River, and as far as White River. There appears to be a structure of some magnitude along this trend, with rather gentle, open folds lying to the west of it and a very sharp syncline to the east. These folds are apparently continuous southward as far as Bull River. Somewhere in the eastern part of the Hughes Range, north and northwest of Fernie, they are all lost, presumably merging there with the southwesterly-trending Bourgeau fault or being truncated by one or other of the great transverse faults of the Hughes Range. The southward plunge of the sector is here carrying it into the proto-Fernie Basin. In the vicinity of White River, the synclines west of the fault-zone expose Beaverfoot limestones, the youngest beds seen in the Mitchell Range.

The nature of the movement along the Stephen-Dennis fault involves an apparent contradiction. The structure in the hanging wall, as seen, for example, on Mounts Burgess, Dennis, and Duchesnay, shows the latest movement to have been one of thrusting from the west. The beds are greatly crumpled and the folds are overturned towards the east; furthermore, the fault dips west wherever its dip is known. Plate 10 shows similar folding and eastward overturning on Hawk Ridge, along the strike to the southeast. However, southward the stratigraphic relations point to a normal fault. At Marble Canyon, the Upper Cambrian Ottertail formation on the west side of the fault has been brought against the Lower Cambrian St. Piran quartzite on the east. The Goodsir group in Hawk Ridge is in fault contact with the Lower and Middle Cambrian of the Mount Ball massif.

This apparent conflict we believe to be the result of the method of elevation of the great panel of rock which forms the Main Ranges sub-province. Following the initial elevation of the panel above the two great converging thrusts, the upper portions of it would be under tension, with the resulting formation of a series of normal faults within the panel. With continued under-thrusting from the west, the plane of the east-dipping Chancellor fault would be raised more and more nearly towards the horizontal (Figure 1), until the limit was reached at which further vertical movement became impossible under horizontally-directed compression. Further thrusts then developed, some or all of them making use, on approaching the surface, of the planes of the earlier normal faults, including the Stephen-Dennis fault. The reversed movements were not sufficient completely to counteract the earlier normal movements. Some of

the resulting compound faults may be comparable with the "pseudo-discoidal" faults described by Link (1928, p. 845). On final relaxation of eastward thrusting, a second spasm of normal adjustment faulting took place locally within the panel, some or all the new gravity faults acting partly or wholly along the planes of the earlier set. Hence a second apparent contradiction, of the Cathedral-Stephen fault (a normal fault) cutting and offsetting the Stephen-Dennis fault (a thrust fault along the plane of an earlier normal fault). There is a similar fault running from below Bath Glacier (east of Mount Daly), across Wapta Lake, and up the valley of Cataract Brook to Biddle Pass. The highway cuts through the beds on either side of this fault, dipping steeply towards one another in spite of the fault plane being nearly vertical. The beds here form the west flank of Narao Peak and the east flank of Cathedral Mountain, and their attitudes suggest periods both of normal and of reversed movement.

As interpreted here, then, the western sector of the Main Ranges sub-province is wholly underlain, at no great depth, by an almost flat fault, the Chancellor fault, which originated as an underthrust from the west. The beds immediately overlying this fault suffered a high degree of shearing, as did also, presumably, those below it. A general "cone of shearing," resulting from such a wedge, has been reproduced experimentally by Link (1928, p. 829). Along the Kicking Horse section, the beds in the sheared zone comprise the lower part of the Chancellor formation. Since, however, the entire western sector plunges to the south, at an angle greater than the pitch of the fault, the shearing affects progressively younger beds southward. At Marble Canyon, it is in the Ottertail limestone, giving the locality its name. Southward from there, it is in the overlying Goodsir shales. Within this group, the shearing is gradually lost at the surface, south of the transverse part of Vermilion River, as the fault plane presumably drops to greater depths.

The deepest exposed part of the sheared belt extends below the east face of the Van Horne Range, and along the longitudinal valleys of the Ottertail and Vermilion Rivers. These two strike valleys are so very straight that it seems extremely probable that they follow the locus of a fault plane, doubtless that of a thrust developed after the first period of normal faulting described above. No actual fault has been discerned in the sheared belt south of Kicking Horse River, but even a major fault could be hidden within such an intensity of shearing.

Highly cleaved but still recognizable beds of the Chancellor formation can be seen at the natural bridge on Kicking Horse River, shortly west of Field. Strongly defined vertical cleavage almost wholly obscures the bedding, which now appears only as colour-banding, nearly horizontal. At Vermilion Crossing, the cleavage dips to the west at about 45 degrees, the faint bedding planes at less than 5 degrees. Excellent road-cut exposures of the strongly sheared and phyllitic Chancellor occur at intervals on the east side of the highway between Emerald and Misko (Plate 20). The equivalent effect on a more massive and resistant formation is seen in the pot-holed Ottertail at Marble Canyon.

The major mountain belt within the western sector of the Main Ranges sub-province lies close to its western margin. It comprises the eastern part of the Van Horne Range, north of Kicking Horse River, and its strike continuations southward, the Ottertail (Vermilion) and Mitchell Ranges. Due to the southward plunge, the beds capping these ranges become progressively younger to the south. The entire body of the Van Horne Range, except for its western face (which belongs in the next sub-province to the west), is composed of beds of the Chancellor formation (largely Middle Cambrian), their red colour being clearly seen from the highway west of Emerald. All the main peaks of the Vermilion Range are dominated by great cliffs of the overlying Ottertail limestone (Upper Cambrian), and the highest among them, notably Mount Goodsir (11,686 feet), are capped by varying thicknesses of the still younger Goodsir group. The latter becomes increasingly dominant southward, and occupies practically the whole width of the southern part of the Mitchell Range (Plate 7). As the Goodsir can

PLATE 9

Looking south at folded Devonian on Cascade and Gibraltar Rocks, 6 miles northeast of Mount Assiniboine. These peaks are in the westernmost Front Range at this latitude. They are underlain by a minor thrust of the Sawback block and overlain by the Castle Mountain thrust. Photograph by M. K. Sorensen.

PLATE 10

Looking south at northeasterly overturned anticline on Hawk Ridge, east of Vermilion Crossing. "Rock Wall" of the Ottertail limestone in right background. **Photograph** by G. G. L. Henderson.

PLATE 11

Detail of breccia of Redwall fault, east of Radium Hot Springs. Note wide zone of crush rock, variety of size of boulders, and selective staining by iron oxide (especially at lower right). Photograph by M. K. Sorensen.

PLATE 12

The Rocky Mountain Trench at Moberly, showing entry of Blaeberry River into the Columbia. North slope of Moberly peak on left, formed of Ordovician sediments. Dogtooth Mountains on opposite side of Trench, exposing Lower Cambrian, and high peaks of Selkirk Range in distance. Photograph by G. G. L. Henderson.

scarcely be described as a mountain-making group, in spite of the huge mass of Mount Goodsir, the Mitchell Range rapidly loses both elevation and ruggedness southward. The arch in the Goodsir persists to the south, however, at least as far as the White River. The synclines within it have by this latitude begun to expose the still younger Wonah and Beaverfoot formations (late Ordovician).

It is to be observed that the western sector of the Main Ranges sub-province is itself readily divisible longitudinally into two parallel portions, in strong contrast with one another physiographically. The dividing line between the two follows the base of the "Rock Wall," which constitutes the central rib of the Ottertail and Vermilion Ranges (Frontispiece). This rib, extending more or less continuously from Mount Hurd to Mount Harkin (both of which are passed at close quarters by the main highways) and including Mount Goodsir, is abruptly distinct in appearance from the eastern part of the Vermilion Range. The eastern part, forming the west side of the longitudinal section of the Vermilion River valley, is composed of rocks of the Chancellor group, weathering into rounded ridges characteristically timbered to the top. East of this again is Hawk Ridge and its strike continuations to Mount Oke (northward) and Tangle Peak (southward). This zone appears to be underlain, south of Marble Canyon, by a contorted arch in beds of the Goodsir group, the arch being itself underlain by the Stephen-Dennis fault (Plate 7). To pass from, say, Foster Peak (Ottertail limestone), across Numa Mountain and the Vermilion valley (Chancellor group) to Hawk Ridge (Goodsir group) has apparently missed out a second "Rock Wall," east of Vermilion valley; the Ottertail formation does not reappear on that side. Thus a westerly-dipping thrust fault is inferred along the west side of Hawk Ridge and for an unknown distance along strike southeastward, the fault displacing sheared Chancellor shales, on the west, against tightly folded Goodsir strata on the east. To the northwest, the fault must lie west of Prospector Mountain; it is presumed to follow approximately the valleys of Ottertail River and Otterhead Creek.

In spite of the fact that the western sector of the Main Ranges sub-province appears to plunge southward throughout its length, that portion lying south of the transverse section of Vermilion River (i.e. the Mitchell Range in the wide sense) becomes rather narrower southward instead of wider. This is an illustration of the generalization made early in this paper concerning the truncation of structures by other structures lying to the west. Southward from Cross River in particular, individual folds within the Mitchell Range appear to converge at an angle of about 10° with the White River Break to the west. Those on the western side of the range seem to be actually truncated by the Break, being lost one by one against the edge of the schist-zone which underlies the upper Kootenay Valley. The Chancellor fault itself presumably pitches to the south with the beds overlying it. However, since the shearing affects progressively younger rocks in that direction, the fault must pitch at an angle rather less than that of the beds above it. Thus the fault trace, also, follows a path to the south gradually diverging westward from the strike of the beds above it, and it must pass below the younger White River Break, possibly in the vicinity of the mouth of Ice River. The only surface beds lying between the Chancellor fault and the White River Break, therefore, lie in a band of contorted and overturned Ottertail (Upper Cambrian) limestones along the western side of the Van Horne Range and on Willowbank Mountain. These limestones are those mapped by Evans (1933, p. 124) as "undivided Middle and Upper Cambrian." The northward divergence of the Chancellor fault from the White River Break is in fact responsible for the existence of the Van Horne Range.

It is within the central part of the true Ottertail Range that the Ice River igneous complex is situated. This is a laccolith-like body of alkaline composition, dominantly nepheline-syenite with melanocratic fractions. A small portion of it can be seen from the highway at Leanchoil, on the crest of the south ridge of Chancellor Peak.

THE WESTERN RANGES SUB-PROVINCE

The Western Ranges sub-province lies between the White River Break and the Rocky Mountain Trench. It thus includes the southwestern face of the Van Horne Range, and the whole of the Brisco, Stanford, and Hughes Ranges. It should probably also, in a strict analysis, include the Galton Range. The sub-province is marked by structures of very great complexity, unlike any other structures known anywhere in the Canadian Rockies. It is also characterized by a stratigraphic succession which does not exist in the first or second front ranges (see p. 75 of this paper).

All the major structures of the sub-province strike about ten to fifteen degrees west of the normal Rocky Mountain trend. As a result, every longitudinal fault and fold within it passes northwestward into the Rocky Mountain Trench, and the whole sub-province wedges out northward. Southeastward the structures converge with the structures of the Front Ranges sub-province, until at Fernie the Western Ranges sub-province abuts against that of the Front Ranges and the whole Main Range is missing. The entire sub-province is bounded, except on the south, by through-trenches eroded largely in sheared rocks of the McKay group.

The White River Break

The White River, which enters the Kootenay from the southeast, derives its name from the white colour of the rocks forming its banks. They are so soft and pale that they were at first thought to be Tertiary lake deposits. They are now known to be highly sheared shales and limestones of Cambro-Ordovician age, the shearing lying along a great fault. This fault has been called the White River Break by Henderson (1954). It forms a major structural division, between the southwesterly *overturned* structures of the Western Ranges and the southwesterly *dipping* structures of the western sector of the Main Ranges. The amount of shortening across the break must therefore be very considerable.

The sheared zone from Whiteswan Lake to Kootenay Crossing is entirely within the McKay group of rocks, which are the approximate equivalent of the Goodsir "formation." However, the two sides of the zone expose different facies of the group. On the northeast side, the cherty facies is present, like that in the Ottertail and Mitchell Ranges. On the southwest side, the beds are of the limestone-shale facies, typical of the whole of the Western Ranges sub-province. The break therefore marks a major stratigraphic division, as well as a structural boundary. The most southerly point at which the zone has been seen is on Bull River, at the mouth of Galbraith Creek. From this point it trends about N. 20°W., gradually swinging more nearly to northwest but within the Hughes Range exerting very little influence on the topography. It passes immediately east of Whiteswan Lake and northward from there it is responsible for the valleys of the White, Upper Kootenay, and Beaverfoot Rivers. It crosses the lower Kicking Horse canyon at its upper end, just east of Glenogle, and enters the Rocky Mountain Trench near the mouth of Blaeberry River. Thereafter the Break appears to coincide with the Trench, perhaps as far as Bush Lakes, in which case it may here converge with a further fault trending still more to the northwest.

South of Bull River the sheared zone cannot be followed with certainty, since this is an area of strong transverse faulting. Possibly, however, it swings into a southwesterly trend and truncates the north end of the Lizard Range, which ends abruptly just south of Iron Creek. If this is the case, the sheared zone must either die out in the region of Sand Lakes (due east of Wardner), or enter the Rocky Mountain Trench somewhere between Wardner and Waldo. Throughout most of its known and assumed extent between Bull River and Bush Lakes, the actual fault zone is hidden beneath thick superficial deposits, mostly river-laid. Where seen, as on Palliser River, it dips west. A westerly dip is also indicated by the topographic trace of the

fault between Leanchoil and Blaeberry, but here it lies immediately beside the east-dipping Chancellor fault. The latter is interpreted as the major underthrust which we conclude must underlie the sheared belt in the western sector of the Main Ranges sub-province (see pp. 31, 32.) Since the southwesterly overturning of the Western Ranges terminates on the northeast against the White River Break, and since any faults related to the southwesterly overturning must dip to the northeast, the southwesterly dipping White River Break must be a younger fault than the northeasterly dipping Chancellor fault. In this case, the Break developed after the uplift of the panel of the Main Ranges, and it may have been contemporaneous with the thrust episode of the Stephen-Dennis and Ottertail River faults. It brings various horizons of the McKay (Goodsir) group, overturned towards the southwest, into juxtaposition with other horizons, including the same group, on the east side, locally overturned towards the northeast. The strata now adjoining one another across the fault are of different facies, though of the same age. They must therefore have originally been widely separated, brought nearer together by the underthrusting, and into final juxtaposition by an overthrust (Figure 1). The westward overturning we interpret as being due to the underthrusting in the footwall of the easterly-dipping Chancellor fault. South of White River, this fault has either died out or is deeply over-ridden by the White River Break. The beds in the eastern part of the Hughes Range are therefore overturned towards the *east,* in the hanging wall of the Break, and not towards the west.

The strata in the sheared zone have been completely pulverized, producing what can only be described as a chloritic, phyllitic mylonite (Plate 21). It is not a true phyllite. Within the pulverized rock there are scattered relict bodies, mostly of limestone, of all sizes and shapes, around which irregular cleavage planes may be deflected. In these characteristics, the sheared Goodsir of the White River Break differs from the sheared Chancellor of the western sector of the Main Ranges sub-province. The unsheared Chancellor is much more argillaceous than the unsheared McKay, and much less calcareous. The shearing of the Chancellor has also been considerably less severe than the shearing of the McKay. As a result, the Chancellor was not pulverized by the shearing; the several sets of cleavage developed in it are much more regular than those in the sheared McKay, and are not interrupted by relict, unsheared blocks to anything like the same extent. The highly sheared Chancellor is a true phyllite (Plate 20), with a much lower chlorite content than in the sheared McKay.

Major Faults in the Brisco and Stanford Ranges

Since all the structures in the Western Ranges converge northward with the Rocky Mountain Trench, the number of individual fault-blocks in the ranges increases southward (Map No. 1). Apart from any consideration of faults lying wholly within the Trench (a possibility which will be discussed in the paper on that subject elsewhere in this guidebook), the Western Ranges are themselves cut by at least three major faults.

The most easterly and the central faults are known respectively as the Stanford and the Redwall faults. Such faults as can be traced west of the latter appear to be possibly part of a third major fault zone, but this lies almost entirely within the Hughes Range, which is poorly known and much cut by large transverse faults.

The Stanford fault is first seen, in the south, east of Kootenay River about eight miles south of the entry of White River, where it diverges with a north-northwest trend from the Redwall fault. Northward, it crosses Kootenay River three miles southwest of the mouth of White River, and continues across the headwaters of Windermere Creek and along the east shoulder of Mount Sinclair. It has not been mapped north of Sinclair Creek, but it probably continues along the east side of the Brisco Range, in general truncating the east limb of the main Brisco syncline (Evans, 1933, p. 147). In the centre of the syncline the Beaverfoot-Brisco limestones form the

main rib of the range as far as Golden. The fault, or a member of the same fault zone, crosses the lower Kicking Horse canyon between Glenogle and Golden and enters the Trench about at Moberly.

The Redwall fault was so named by Evans (1933, p. 147) because its great band of red, hematitic fault-breccia forms the red cliffs on the two sides of the highway just east of Radium Hot Springs. The same breccia gives Redstreak Mountain its name. The fault is first seen in the south between Whiteswan Lake and Kootenay River, ten miles east-northeast of Canal Flats. Northwestward from the point at which the Stanford fault diverges from it, the Redwall fault exhibits a remarkably straight course along the length of the Stanford Range, gradually converging with the Rocky Mountain Trench. It enters the Trench about three miles north of Sinclair Creek, and thence appears to pass between Jubilee Mountain (an intravalley ridge within the Trench) and the Brisco Range. There must be a fault of major displacement between these two points. Beyond them the fault is lost in the wide part of the Trench. It appears to be on strike with the "great fault" described by Daly (1915, p. 113) as running along the front of the Dogtooth Mountains. If the two were a single continuous fault, it would be the only *longitudinal* fault known to cross the Trench, and it would have to converge northward with the White River Break. However, this continuity would require the fault to change along the strike from being a major transcurrent fault to being a westerly-dipping thrust fault. It would also have to change from bounding, on the east, a belt of strata overturned to the west, to bounding a belt overturned to the east. The continuity across the Trench is therefore, almost certainly, more apparent than real. As we will show elsewhere in this guidebook (pp. 93, 94), it can be accounted for by the convergence of a younger fault from the south.

Unlike the Stanford fault, the Redwall fault appears to have the older rocks on its west side throughout its length. In both faults, however, the trace is so straight across topography that each must be sensibly vertical for a considerable depth. The Redwall fault-breccia can be seen to be so over a vertical interval of at least 4000 feet. This fault has been proved by Henderson (1954) to be essentially a transcurrent or strike-slip fault, though it no doubt has a vertical component of some magnitude in addition. Transcurrent movement on the Stanford fault is also made virtually certain by the stratigraphic relations, which will be described later in this paper (p. 66). Structural relationships make it clear that the Redwall fault is sinistral —that is to say, the west side has moved relatively to the south, the offset being at least five miles. The Stanford fault, on the other hand, is dextral. The net effect is therefore that the inter-fault block has moved relatively northward with respect to the blocks east and west of it.

Major Faults in the Hughes Range

The main northwest-southeast trending faults in the Hughes Range have not been adequately mapped. The structure of the range is highly complex, and differs from that of any other Rocky Mountain range in the abundance of large cross-faults of considerable displacement (in some cases apparently over 20,000 feet, according to Rice, 1937, pp. 26-30). Most of these trend about east-northeast, and they are younger than the longitudinal faults, which they offset. The most northerly large representative of the transverse group cuts across the north end of the Hughes Range about at Canal Flats. Others occur at intervals southward into Montana, and some of them apparently cross the Rocky Mountain Trench without offset.

As a result of the transverse faults, no single fault of northwest-southeast trend can be traced continuously along the length of the Hughes Range. The largest fault seen with this trend crosses the headwaters of Tanglefoot Creek, immediately east of Mount Fisher, the prominent pyramidal peak towering above the Trench opposite Cranbrook. It has been traced to the northwest across the headwaters of Wildhorse Creek, east of Wasa, and may continue

thence to Lussier (Sheep) River. Southeastward, it is probably cut off by the great transverse fault which runs across the north shoulder of Hungary Peak. If so, its trace to the south of this fault should be offset to the east, since it is a westerly-dipping fault and this transverse fault is an upthrust from the north. The longitudinal fault may be the same fault as that crossing Bull River east of the Steeples, and this again may be the same one as that truncating the west limb of the Lizard Range. This latter fault crosses Elk River two miles east of Elko, is offset by a further transverse fault south of Mount Broadwood, and continues, four miles or so east of Wigwam River and parallel to it, into Montana. Whether or not all these known longitudinal faults represent off-set portions of a single fault, all have brought Purcell rocks, on the west side, against various Palaeozoic horizons on the east. South of Elk River, the upper Purcell is brought against Rundle limestones; on Bull River, older Purcell rocks rest against probable Ordovician (McKay group); on Wildhorse Creek, Creston quartzites are in contact with Cranbrook (Lower Cambrian) quartzites. The fault, or faults, are all thrusts from the west, the beds on both sides plunging southward.

No fault can be mapped along the west face of the Hughes Range, overlooking the Trench, but the abrupt wall there certainly suggests a bounding fault of great displacement. This is presumed to be the Bull River-Sheep River fault of Schofield (1921, p. 93).

The Fault-blocks within the Western Ranges

The major longitudinal faults described above divide the Western Ranges sub-province into a number of fault-blocks, each characterized by a distinct set of structures. Because all the faults trend obliquely to the Rocky Mountain Trench, and two of them converge, the number of fault-blocks varies for different parts of the sub-province. In the Stanford Range, a maximum of three are present. Northward, in the Brisco Range, only the eastern and central blocks of the Stanford Range are seen, because the western block disappears into the Trench shortly north of Sinclair Creek. To the south, in the Hughes Range, only the eastern block of the Stanford Range can be traced with certainty, as both the central and western blocks are interrupted, on Kootenay River, by a large triangular area of down-faulted younger rocks (largely Siluro-Devonian gypsum). It is probable that subdivisions do exist within the Hughes Range, though they may not be the same as those farther north. The westernmost structures in the Hughes Range, in particular, trend into the Trench before reaching the Stanford Range.

The western block of the Stanford Range, between the Redwall fault and the Trench, is highly faulted and folded, the folds being slightly overturned towards the southwest. The southern part of the block is occupied by oblique-trending thrust sheets. A minor fault within this block, cutting Beaverfoot dolomite, is perfectly seen in the famous road-cut at Sinclair Canyon, just west of Radium Hot Springs.

The central block of the Stanford-Brisco Range, between the Redwall and Stanford faults, includes the two main ribs of the range. In the Stanford Range it consists of generally upright, anticlinal folds separated by faulted synclines. Further north, in the Brisco Range, the continuation of the belt is dominated by two great longitudinal synclines, with only minor faulting. Both synclines contain the mountain-forming Beaverfoot and Brisco formations of limestone and dolomite. One rib enters the Trench just south of Spillimacheen. The other, the "main Brisco syncline" of Evans, runs the whole length of the range to enter the Trench a short distance south of Golden. Going northward along this syncline, the folds are progressively more strongly overturned towards the southwest. Some of the minor faulting in the southern part of this central block is of economic significance, since it has allowed the preservation of at least one down-dropped block of younger Palaeozoic strata containing very thick and pure gypsum.

The eastern block, between the Stanford fault and the White River Break, forms the eastern flank of the Stanford and Brisco Ranges. In the former, it is occupied by the lower limb of a major recumbent anticline overturned towards the west. In places this fold is marked by large nappe-like drag folds, also overturned towards the west. Eastward across this block, progressively older beds are met; there is also a concomitant eastward increase in the intensity of shearing. Eventually, highly sheared and almost unrecognizable McKay passes into the schist zone along the White River Break.

Thus the western rib of the Brisco Range at Golden is the eastern rib of the Stanford Range at Windermere. At the latitude of the north end of Windermere Lake, the axis of the Brisco syncline lies eight miles east of the Trench, at right angles to the strike; at Golden it underlies the Columbia River.

The structure of the western rib of the Hughes Range lies within a fault-block west of any block in the Stanford or Brisco Ranges. It comprises the faulted west limb of an isoclinal syncline, slightly overturned towards the east and cut in a very complex manner by transverse faults. The general appearance of the range, from the west, is therefore that of a great ridge with steep westerly dip, but the younger beds (Cambrian) are on the east side of the ridge.

The Galton and Macdonald Ranges

As we have already seen, the Lizard Range, west of Fernie, is a member of the Front Ranges sub-province backed by a fault which is part of the Western Ranges sub-province. This fault farther south marks the eastern boundary of the Galton Range; moreover, it is certainly a thrust fault, and not a normal fault as indicated by Daly (1912, Pt. III, Sheet 2). Between it and the Flathead Valley is a belt dominated by much younger rocks, considerably faulted and overturned towards the east. About this belt, which includes the Macdonald Range, we know almost nothing at first hand, and can only comment that it appears to be part of the same longitudinal fault-block as the Fernie Basin, which originated as a structurally low area at least in pre-late Devonian times. Thus, although the Macdonald and Galton Ranges lie immediately adjacent to one another, the first is part of the Front Ranges sub-province and the second belongs to the Western Ranges.

THE ROCKY MOUNTAIN TRENCH

The Rocky Mountain Trench is the most prominent single lineament in the Rocky Mountain system, of which it forms both the actual and the official western boundary. Unlike the mountains to the east, the Trench has been generously treated in the literature. Also unlike the mountains, the Trench has suffered more interpretation than it has provided facts. A summary of previous views on it is desirable before any new suggestions are offered, and the Trench is therefore made the subject of a separate paper in this guidebook. It will not be treated further in this one.

STRATIGRAPHY

INTRODUCTION AND GENERAL

The main corpus of published stratigraphic data, for the Main Ranges sub-province and for the Sawback Range, is due to Walcott. All of his sections are embodied in a single great posthumous paper. The only important contributions post-dating that paper are those of Deiss and of Rasetti, both dealing exclusively with the Cambrian, and largely with the Middle

Cambrian, of a restricted area of the Main Range.

For the Front Ranges, other than the most westerly fault-block, considerable data is available, both in the publications of the Geological Survey and in the files of oil companies. For the Western Ranges, the stratigraphy was established by Walker, and the structure treated in splendid fashion by Evans.

Walcott's long series of publications on the Canadian Rockies was accompanied by a notable duel with Lancaster Burling, very easily the finest Cambrian stratigrapher and palaeontologist ever produced by Canada. Subsequent students of the area have come to realize that, in every point at issue during this long debate, Burling was right and Walcott wrong. This fact in no real way lessens the debt owed to Walcott. It was he who first drew attention to the perfection of the exposures in many localities, and to him that we owe the basic subdivision of the Precambrian, Cambrian, and Ordovician strata into formations which we still use. The magnificent photographs alone would make the posthumous paper of 1928 indispensable to any geologist wishing to familiarize himself with the stratigraphy of the Rockies.

This is so apparent that the reader may be bewildered by the constant contradictions of Walcott's facts and figures, which have appeared before in the works of Burling and of Deiss, and will appear frequently in the remainder of this paper. It is therefore necessary to begin with some attempt to justify the utter rejection of the legacy of much of Walcott's detail, including his palaeontological detail.

Walcott's sections, as published by Resser, give the impression of careful measurement and description. In actual fact, Walcott measured scarcely anything, in the sense in which a modern geologist understands the process. His method was to traverse *around* sections, formation thicknesses being computed roughly or measured approximately in stages. The totals were then given to the nearest foot, thus giving an impression of accuracy. Since the attitude of the beds was imperfectly allowed for, and small folds or faults were missed completely, this alone allowed of considerable error. During these traverses, fossils were collected largely from talus blocks, and their positions in the section guessed at from the lithology, unless they were of such importance (as in the case of the Burgess shale fauna) that their discovery in place was imperative.

Where portions of excellent sections were inaccessible without long climbs, Walcott would move to other localities nearby where the required portions dropped nearer to valley level. Here he would continue the section as if it were part of the earlier one, and include portions from several different localities in a single section without saying so. This not only involved frequent serious overlap or omission by inaccurate tie-in; it also meant that, where some facies change, such as dolomitization, had occurred between the localities, Walcott would include an entire formation, or a large part of a formation, twice in the same section, with each entry given its maximum thickness. Where a major facies change occurred—and there appear to be several in the area, as will be seen shortly—the entire section would be added bodily to those measured elsewhere. This refusal to acknowledge a facies change (a refusal well illustrated by pp. 226-239 in the 1928 paper, and particularly by the references to Walker's Windermere memoir) led Walcott to postulate five completely separate "troughs" within the Rocky Mountain "geosyncline" during early Palaeozoic time. Deposition was envisaged as taking place sometimes in one, sometimes in another. This is not a theory to commend itself to most geologists.

The consequences of this technique were that thicknesses were often greatly overestimated in the first place; and that purely local facies developments were elevated into formations and *added* to the sections without Walcott realizing that they *supplant* some other part of the

formation within which they occur. Thus the Cambrian section came to be regarded as comprising the following formations, in descending order:

(Ordovician above)

		Thickness in feet
	Ottertail	1725+
	Chancellor	4500+
Upper	Sherbrooke	1375
Cambrian	Paget	360
	Bosworth	1587
	Arctomys	268
	Eldon	2728
Middle	Stephen	640
Cambrian	Cathedral	1595
	Ptarmigan	426
	Mount Whyte	390
Lower	St. Piran	2705
Cambrian	Lake Louise	105
	Fort Mountain	1325

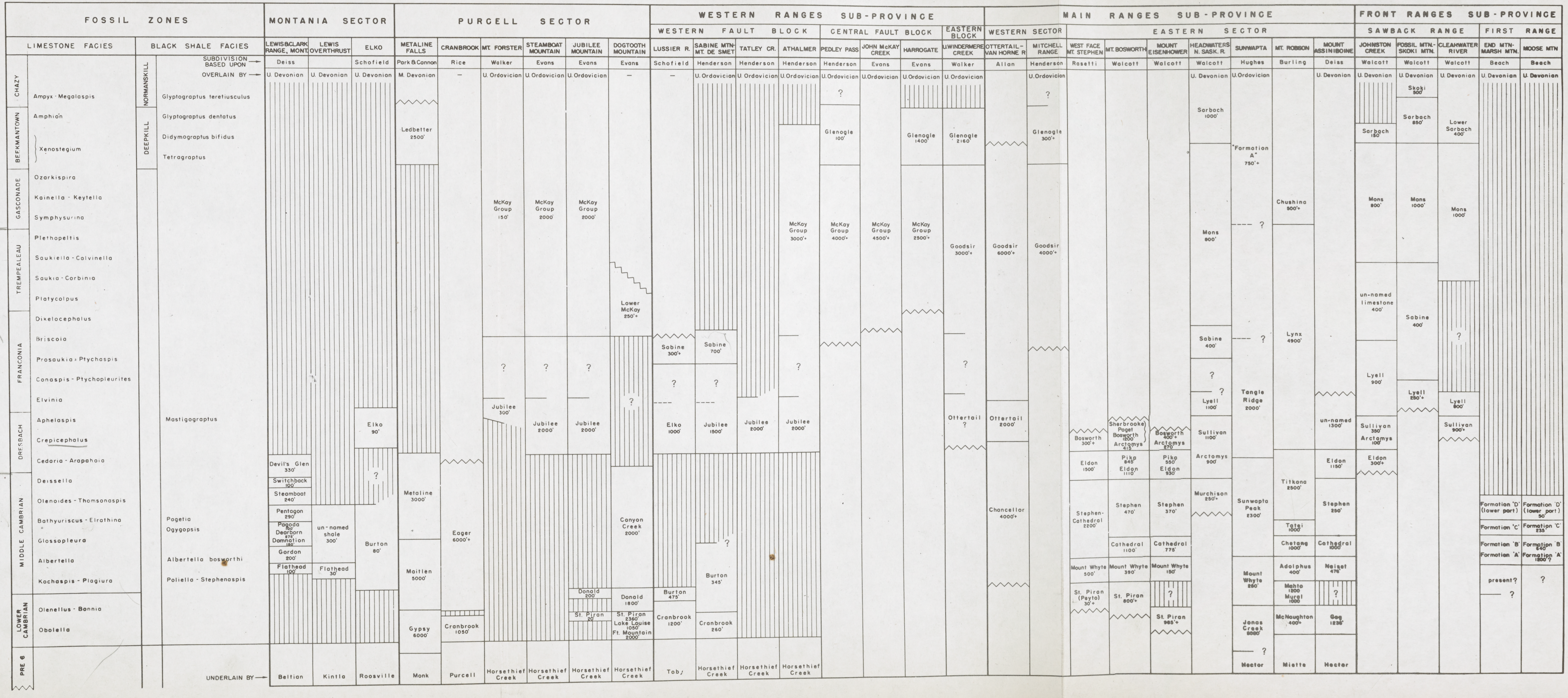
(Precambrian below)

This provides a total of just under 20,000 feet, an oft-quoted figure, and it excludes a considerable thickness of the overlying Goodsir group, then thought to be wholly Ordovician but now known to extend well down into the Upper Cambrian. Allan (1914, p. 60) gave figures totalling 28,168 feet (largely from Walcott) for the lower Palaeozoic succession. As recently as 1947, Canadian authors have continued to assert that the Cambrian in the Bow River section exceeds 18,000 feet in thickness. Walcott's final figure (1928, p. 199), *for the upper Cambrian alone,* was 15,955 feet.

This is nonsense. No Cambrian section is known in Canada, south of the Columbia Icefields, with a thickness reaching 10,000 feet. In the Ottertail Range, where the top of the Cambrian lies in an uncertain position within the Goodsir group, and the base is not seen, the maximum for the southern Rockies may be reached, and it may exceed 10,000 feet, but it cannot do so by much. The thickest Cambrian section known anywhere in Canada is that in the Mount Robson area, where it amounts to about 13,000 feet.

Four of Walcott's formations have no validity as independent sedimentation units. The Sherbrooke, Paget, and Ptarmigan "formations" are local facies equivalents of other named formations, as will be described shortly. The Lake Louise "formation" is one of a number of locally developed shale lentils. The Chancellor formation is undoubtedly valid, but it can scarcely occupy the position indicated by Walcott, and must be the lateral equivalent, on the western side of the shelf, of some other formation or formations (see pp. 48, 49). The true succession in the Main Range, with average thickness, is:

CORRELATION OF CAMBRIAN AND LOWER ORDOVICIAN FORMATIONS
CANADIAN ROCKY MOUNTAINS AND ADJACENT AREAS



		Thickness in Feet
	Lower Goodsir	1000 or more
Upper	Lyell	1000
Cambrian	Sullivan	1000
	Arctomys	400
	Pika	700
Middle	Eldon	1100
Cambrian	Stephen	450
	Cathedral	1000
	Mount Whyte	350
Lower Cambrian	St. Piran	2000

Thus the thickness of the Cambrian section is just about half that quoted in the most recent publications. A comparison between this section and that given by Walcott reveals examples of both duplication and overestimation of thickness in the latter. The classic example of overestimation is at Walcott's type Cambrian section, on Mount Bosworth. Most geological students have been told that Walcott measured "over 12,000 feet of comformable strata" on this mountain, and this phrase occurs both in Walcott's own work (1928, Plate 67) and in a well known text book. The strata he measured have an average dip of 20 degrees across a mountain with less than 4,000 feet of relief. The lower slopes are covered by trees, and the east ridge, which must be climbed if the older beds are to be measured, is cut by a fault which Walcott did not see. It is, consequently, geometrically impossible for the visible thickness of beds in the mountain to exceed 6000 feet, and the addition of a small amount of younger sequence on Paget Peak still cannot bring the total to more than 7,000 feet.

An illustration of the "problem of additive facies" is seen at the type section of Walcott's Ptarmigan formation, on Ptarmigan Peak in the Slate Mountains. Walcott's thickness of rather more than 400 feet is correct for the dark-coloured limestones which he established as the Ptarmigan formation (1928, pp. 278-9). But he took it for granted that the overlying Cathedral formation would still retain its normal thickness, regarded by Walcott as being in excess of 1500 feet. Since, however, the Ptarmigan "formation" is merely a local facies development of the lower part of the Cathedral formation, which is typically no more than 1200 feet thick, the two "formations" combined total only about 1,000 feet in thickness. To make the matter worse, Rasetti has shown (1951, p. 65) that the lower part of the "Ptarmigan formation," in its type section, actually belongs to the underlying Mount Whyte formation. We thus have the sequence of beds on Ptarmigan Peak, from the top of the Cathedral formation to the top of the St. Piran quartzite, totalling 1350 feet, plus or minus a few feet; Walcott's figure for the same sequence, on the same mountain, was 2868 feet.

A similar situation is that of the Sherbrooke and Paget "formations" in the Upper Cambrian of the Mount Bosworth area. These constitute merely extremely local oolitic developments in the upper part of the Bosworth limestone. They were measured by Walcott on different ridges, and because they looked a little different he elevated them into separate formations. They have never been recognized in any other section, not even by Walcott himself, because a very small shift in any direction finds the oolitic bands in different parts of the Bosworth limestone. The entire interval between the base of the Bosworth formation and that of the great Lyell limestone (both of which are described later in this paper) is occupied by a carbonate sequence, consisting mostly of thinly-bedded blue limestone with intervals of oolitic and argillaceous limestone

and some shale. This sequence makes up Walcott's own Sullivan formation in the area north of Bow Lake, and its typical thickness is about 1000 feet. It may be quite a lot thicker than this west of Mount Bosworth, but Walcott's figure of 3322 feet is greatly excessive.

The most puzzling single problem in the Cambrian stratigraphy is afforded by Allan's Chancellor formation. When originally described (1914, pp. 75-84) it had been seen only between the Stephen-Dennis fault and Kootenay River. As the formation is utterly different in appearance from anything in the Bow Range, and is moreover not diagnostically fossiliferous, Allan and Walcott assumed that it was part of a younger series, and added the entire succession of the Ottertail Range bodily on to the top of that in the Bow Range. No published data has ever cast doubt upon this, though Resser appears to have realized that something was amiss (Walcott, 1928, p. 200, footnote).

If one moves into the Sawback Range just east of Mount Eisenhower, or northward along the main range towards the Columbia Icefield, a complete succession is perfectly exposed from the top of the Middle Cambrian up into the Ordovician. There is still nothing which looks like the Chancellor formation, and, in fact, no Upper Cambrian succession is known, in the southern Rockies, of a thickness equalling that of the Chancellor formation alone.

One of two explanations is therefore called for. Either the Chancellor is a great lens, dominantly of shale, deposited in the Ottertail belt whilst deposition was suspended in the Main Range proper (Walcott, 1928, p. 187), or it is the lateral equivalent of some Main Range formation or formations. As the ranges along the Continental Divide show an apparently unbroken succession of Cambrian and Lower Ordovician beds, including all fossil zones and reaching about the maximum thickness for the Cordilleran Province, it is difficult to believe that a whole formation could be unrepresented there. The likelihood, therefore, is that one or more formations from the Main Range proper are the stratigraphic equivalent of the Chancellor. The problem is to discover which they are, as throughout its type belt the Chancellor formation has no visible base.

The series overlying the Chancellor—the Ottertail formation and the Goodsir group— are directly correlatable with series both on the Continental Divide and in the Western Ranges. On the former, in the area north of Bow Pass, the combined Lyell and Sullivan formations are patently the equivalent of the Ottertail, and the overlying Mons and Sarbach are equivalent to part of the Goodsir—though the Goodsir extends much lower, faunally, than the lowest faunal zone of the Mons. In the Western Ranges, the Jubilee limestone of Evans (1933, pp. 124-5) is the Ottertail formation, and was mapped under this name by Walker (1926, p. 21). The overlying McKay group contains exactly the same faunal zones as the combined Mons and Sarbach of the Main Range, and was mapped as Goodsir by Walker. It seems fair, therefore, to start from the possibility that the top of the Chancellor is about the equivalent of the Arctomys formation of Mount Bosworth and northward, as this unit comes next below the Ottertail equivalent there. This is highly satisfactory, as the top of the Chancellor is characterized by bright-weathering thin beds—red, yellow, and purple; so too is the Arctomys.

However, the Arctomys of the main range is underlain by some 3600 feet of Middle Cambrian strata, of which nearly 3000 feet are dolomite or limestone. There are a number of notable interbeds of bluish limestone, and some dolomite, in the Chancellor formation, but the great bulk of the unsheared portion consists of shales and argillites. On Park Mountain, however, which lies along strike from Mount Stephen and six miles to the southeast, the great Eldon dolomite of the main range has given way entirely to a series of interbedded siliceous shales and argillaceous limestones, with only lenses of the dolomite which normally makes up the entire formation (Rasetti, 1951, pp. 34-5). On Mount Stephen itself, the Eldon forms a great part of the upper peak, and is a dolomite, though some beds of siliceous shale have appeared. Below

the Eldon, however, there is virtually no dolomite left. A thickness of over 2500 feet of siliceous shale, with interbeds of dark gray limestone, represents the whole of the Stephen and Cathedral formations and the upper part of the Mount Whyte formation (Rasetti, 1951, pp. 43-45, 68-9). Fortunately, many of the limestone beds are highly fossiliferous, and the age-equivalence of the sequence is not in doubt. A little above the top of the Mount Whyte, some lenses and blocks of dolomite occur within the shale-limestone series, but otherwise the transformation of the Cathedral formation is complete.

Thus we have localities at which both the Eldon and the Cathedral carbonate bodies have given way westward to thinly-bedded argillaceous series whilst still on the east side of the Stephen-Dennis fault. When the crustal shortening represented by this fault is taken into account, there is little reason to doubt that the equivalent formations west of it may be entirely of the argillaceous facies. This, however, does not solve the problem of the age of the beds below the Chancellor formation in the Ottertail block, because no older beds crop out there. In the southern part of the Western Ranges, however, the entire interval between the Ottertail formation (there called Jubilee) and the Lower Cambrian quartzites (there called Cranbrook) is occupied by a bright-weathering argillaceous series closely resembling the Chancellor. Moreover, in the area immediately northeast of Cranbrook, it is almost of the same great thickness. The base of this series, which is here variously called the Eager or the Burton formation, contains the fauna of the *Olenellus* zone, elsewhere characteristic of the Lower Cambrian portion of the old Mount Whyte formation. We thus have powerful evidence that the Chancellor formation is the age-equivalent, in another facies, of the beds in the main range extending from Mount Whyte (in Walcott's sense) to Arctomys inclusively. Thus it embraces the whole of the Middle Cambrian, plus the very base of the Upper and the very top of the Lower Cambrian. The term "Chancellor group" would therefore be better than the term "Chancellor formation."

These notes offer our justification for treating the Cambrian stratigraphy in a manner very different from that commonly adopted. The individual Palaeozoic formations are dealt with in the remaining sections of this paper. Figure 2 shows a suggested correlation of these formations, in all the sub-provinces and portions of sub-provinces referred to here, lying between the eroded top of the Precambrian and the top of the Lower Ordovician. The Upper Ordovician, Silurian and Middle Devonian involve very few formations in comparatively restricted localities, and it is felt that their age relationships are adequately dealt with in the text. Beds of late Devonian, Mississippian, and later age, so important in the Front Ranges, have been extensively treated in the literature, as well as in the Society's guidebook for the 1953 Field Conference. They are therefore treated only very briefly in the present work, and the Mesozoics not at all; a short bibliography of Front Ranges geology is being offered in place of further descriptions of them.

The correlation chart reveals the great number of names employed for some formations which are clearly correlative, as well as for others which can reasonably be considered to be so. This introduces the problem of priority of nomenclature. Stratigraphical nomenclature should theoretically be bound by rules as stringent as those governing zoological and palaeontological nomenclature. However, the authors have no intention of setting themselves up as arbiters in the matter. This paper is for the use of field geologists, and we have used the formational names which seem the most appropriate for use in the field. The confusion that would result from a rigid adherence to the principle of priority is illustrated by the fact that it would require the abandonment of Beach's Palliser and Fairholme formations in favor of the Pipestone and Messines, respectively, of Walcott. This would be a tiresome departure from very common usage, and one to be avoided if the nomenclatural pundits will allow it.

PRECAMBRIAN

The Rocky Mountains expose sections of both the great Cordilleran Precambrian series, the Purcell and the Windermere. The former occurs, presumably, in all sub-provinces, as well as in the ranges west of the Rocky Mountain Trench. The Windermere series occurs at the surface as far east as the Castle Mountain thrust. North of Crowsnest Pass, no rocks of Precambrian age appear at the surface in the Front Ranges sub-province. Some Precambrian sediments underlie the southwestern Alberta plains, but whether they belong in the Windermere or the Purcell is not known.

The only Precambrian beds seen at the surface in the Front Ranges overlie the flat salient of the Lewis overthrust in Waterton Park. There, and, still better, south of the border in Glacier National Park, splendid sections of the Beltian or Purcell series are seen on nearly all peaks. The Windermere series is not present in this area.

In the Main Range, the Hector and Corral Creek formations underlie the wide anticline along upper Bow Valley. Their outcrops stretch southward in a narrow band to Mount Assiniboine; westward to Vermilion Pass; northward beyond Bow Pass; and eastward to the Castle Mountain thrust. Exposures are poor, however, except around the bases of some of the Mountains. The Hector formation appears to be the equivalent of all or part of the Horsethief Creek formation of the Windermere series. It is commonly the lowest formation exposed in the hanging-wall of the thrust along the east front of the Slate Mountains, for instance, and at Mount Assiniboine. The age of the Corral Creek formation is not known; it may equate with some older part of the Windermere series than the Horsethief Creek, or it may be an eroded portion of the still older Purcell.

In the western sector of the Main Ranges sub-province, no beds of Precambrian age are seen at the surface. Nor do they appear in the eastern or central fault blocks of the Stanford Range. In the westernmost block, however, beds of Windermere age (Horsethief Creek formation) form the base of the exposed series, increasing in amount of exposure southward. Passing southward into the Hughes Range, the oblique trend of the structures brings both Windermere and Purcell rocks into the east wall of the Trench. All horizons of the upper Purcell series are represented in this range, making up the major part of the main mountain rib of Vertical Mountain, Mount Fisher, and the Steeples. Crossing Elk River Canyon, they continue southeastward into the Galton Range, and beyond into the United States.

In the Trench area, similarly, and west of it, the Windermere series is the dominant exposed part of the Dogtooth Mountains and the intravalley ridges. With intruded acidic stocks it makes up most of the Purcell Range, with the Purcell series proper becoming dominant southward towards Kimberley.

Apart from observations on the Windermere series by Henderson, incidental to his work in the Stanford Range, neither of us has made any proper study of the Precambrian outcrops. We therefore cannot make any useful contribution to their understanding, and must be content to offer a short bibliography of the chief publications on the subject. This bibliography follows at the end of the paper.

LOWER CAMBRIAN

The Lower Cambrian is dominated by orthoquartzites, with green and purple slates and phyllites becoming more abundant westward. The quartzites are either gray, or purplish and pink, commonly banded. A typical mineralogical feature is the abundance of small flecks of limonite, apparently derived from pyrite cubes and octohedra. The quartzites represent the basal unit of the great early Cambrian transgression over the eroded Beltian and Windermere surfaces.

A comparison of the limits of this transgression, for the three sub-divisions of the Cambrian in turn, is an instructive study in the development of the Cambrian depositional basin. Our present evidence is that Lower Cambrian deposition extended very much farther to the west than that of any succeeding early Palaeozoic period, and correspondingly less far to the east. There appears to have been a small area of Lower Cambrian non-deposition, perhaps a positive area, in the region of Radium, Fairmont, and Horsethief Creek. The effects of this area will be made apparent in each of the succeeding sections. Also, of course, there was old Montania, more extensive in early Cambrian times than in any succeeding period. With these interruptions, however, Lower Cambrian quartzites and phyllites are known to have extended into the Ingenika River area (Okulitch & Roots, 1949, pp. 37-46); the Cariboo District north of Quesnel Lake (Lang, 1938, pp. 13-14); the eastern Selkirks; and southwestward into the Moyie Range and thence along the Colville Embayment into Washington State. In other words, early Cambrian seaways probably extended as far west as the area of the so-called Shuswap terrain, and possibly west of Kootenay Lake. Across this whole belt, the transgression deposited quartzites directly over different horizons in the Windermere series. It is now very difficult to be sure which of the quartzites are Windermere and which early Cambrian in age, since they represent an unfossiliferous facies. However, Okulitch (1949, pp. 16-20) has persuasively argued the case for regarding Daly's Summit Series, in the Selkirk Mountains, as diachronically transgressing the Windermere-Cambrian time boundary. The actual deposits in the eastern Selkirks and in the Dogtooth Mountains will be described later in this section.

Two points should be noted regarding this first Palaeozoic transgression. The next oldest formations to be represented so far west of the Rocky Mountain Trench, at the present time, are of Carbo-Permian age— variously called the Cache Creek or Slide Mountain group or series— and these are everywhere in part volcanic. Thus it is probable that post-early Cambrian seaways were more restricted on the west; it is virtually certain that neither Silurian nor upper Devonian sediments were ever deposited in the present Selkirk-Purcell-Cariboo territory. On the other hand, every post-early-Cambrian horizon, except the Silurian, had a greater eastward and southward extent than had the Lower Cambrian deposits. Thus the general tendency of pre-Mississippian seaways appears to have been towards an eastward migration. The uplands west of the Trench, like Montania to the southeast and Peace River Island to the north, resisted complete transgression until mid-late Palaeozoic time.

In the southern Rocky Mountains, beds of early Cambrian age have nowhere been proven to exist in the first three front ranges at these latitudes, though they may crop out in the immediate hanging wall of the McConnell fault north of End Mountain. They are also seen at the surface in the last of the front ranges immediately north and south of the Assiniboine massif —in Simpson Ridge and the main rib of the Royal Group. A full development characterizes the Main Range almost throughout its length. From Mount Robson to Jasper, and southeastward along both sides of the Jasper-Banff highway, the lower cliffs of a great many mountains are formed of thick quartzites. The Lower Cambrian is here about 3000 feet thick, and in most localities carries a good deal of limestone in the centre, with *Olenellus*. Since the Main Range over this section is plunging to the south, to its pitch-depression underlying the Columbia Icefields, the Lower Cambrian goes below ground and is not seen in the great mountains at the headwaters of the Saskatchewan River. Here the Middle Cambrian limestones are the oldest beds exposed.

Farther south, the quartzites reappear at Waterfowl Lakes and are well exposed around the base of Mount Patterson. Thence southward they form the lower cliffs of virtually all peaks on both sides of Bow Valley. In the Slate Mountains, the broad bases of Mount Hector and Ptarmigan Peak expose some 1700 feet of quartzite, resting upon the eroded Hector formation of Precambrian age. Redoubt Mountain (formerly called Fort Mountain), east of the Lake Louise turn, is the type-locality for the basal unit. Some 2000 feet are exposed around the base

of Mount Temple, and just over 1000 feet on the front face of Mount Eisenhower, the base not seen in either locality. The last appearance of the quartzite southward, along the Continental Divide, is in the Assiniboine massif, where it has thinned to a total of 1235 feet (Deiss, 1940, pp. 762-764), apparently without any fossiliferous interbeds.

Along the Kicking Horse route, the last glimpse of the quartzite going westward is in the bases of Mounts Stephen and Burgess. It is through the upper part of the quartzite, in the base of Cathedral Mountain, that the upper spiral tunel of the Canadian Pacific Railway line is cut. On the Vermilion route, the quartzite is last seen in the great cliffs encircling the bases of Storm Mountain, Mount Whymper, and Stanley Peak. The Lower Cambrian section on Storm Mountain is complete.

The Lower Cambrian is nowhere exposed in the Mitchell or Ottertail Ranges. It should appear somewhere in the Van Horne Range, up the plunge, and the thickness of Chancellor beds exposed on Mount Deville suggests that the quartzite should come into view very shortly north of the headwaters of Glenogle Creek. In the Western Ranges, the oldest beds seen in the eastern and central fault blocks are of late Cambrian age, but the quartzites of the Lower Cambrian appear in part of the western block, overlooking the Rocky Mountain Trench. They here comprise the Cranbrook formation. It first appears, going south, a few miles southeast of Fairmont Hot Springs, and thickens rapidly southward. The quartzite portion proper is about 250 feet thick on Mount de Smet, east of Canal Flats; 675 feet on Grainger Mountain, only two miles further south; and over 1000 feet on Lussier River, southwest of Whiteswan Lake. All these outcrops rest on Windermere beds or on eroded upper Purcell.

On the west side of the Rocky Mountain Trench, and on the intravalley ridges within it, the quartzite apparently behaves in the opposite manner. In the Sir Donald and Hermit Ranges of the Selkirk Mountains, the Horsethief Creek series, of Windermere age, is overlain by the great Hamill quartzite, which forms the horn of Mount Sir Donald. Some or all of this formation is very probably of early Cambrian age. On the opposite side of Beaver River, near the northern end of the Dogtooth Mountains, Evans (1933, pp. 119-123) measured 7000 feet, or more, of quartzites with green and purple slates and phyllites, all probably referable to the Lower Cambrian and carrying *Olenellus* in a Peyto limestone equivalent at the top. This series thins southward, to about 3000 feet near the southern end of the Dogtooth Range, about 250 feet on Jubilee Mountain, and zero on Steamboat Mountain. In the front ranges of the Purcell system, opposite Radium, the Lower Cambrian is likewise absent, a thin Ottertail limestone resting on Windermere. However, the early Cambrian quartzites reappear on this west side of the Trench somewhere south of Skookumchuck Creek. They are about 1000 feet thick in the inliers north and east of Cranbrook, and they there contain a body of remarkably pure magnesite.

In the Trench area, therefore, we have the Lower Cambrian thickening, on both sides of the Trench, southward from an apparently positive area occupying the stretch about from Fairmont to Spillimacheen. Northward from this area of non-deposition, it again thickens on the *west* side of the trench, and there contains a good deal of argillaceous material. We may, therefore, reasonably conclude that the northern end of the Brisco Range, between Harrogate and Golden, is underlain at depth by beds of early Cambrian age, thickening northward. We also see that the zone of maximum argillaceous content in the Lower Cambrian was more or less in coincidence with that in the Middle Cambrian (which is nearly all argillaceous west of the Stephen-Dennis fault). The unseen Lower Cambrian beds below the Ottertail Valley and Range are therefore probably more argillaceous than those in the Bow Range. If so, the first formation to be deposited throughout the Southern Rockies without a marked change in facies, or thickness, or both, was the Upper Cambrian Ottertail limestone.

The Cranbrook occurrences of the early Cambrian quartzites were deposited in a narrow trough flanking the western side of the Montania of this period. Hence they thin rapidly eastward, to only three or four feet of hematitic conglomerate at Elko; and thicken to the southwest, along the axis of the "Colville Embayment" of Deiss (1941, pp. 1099-1101). In the northeastern corner of Washington State, the thickness of the Lower Cambrian reaches its probable maximum on the continent, at least 6000 feet and probably over 10,000 feet (Park & Cannon, 1943; Campbell, 1947). Eastward we pass on to old Montania, and find no Lower Cambrian whatever in the Lewis overthrust sheet in the vicinity of Waterton and Glacier Parks. Throughout this sector, and southward into Wyoming, a basal Middle Cambrian sandstone rests disconformably upon the red and green argillites of the Beltian.

Shortly before the close of early Cambrian time, coarse sand deposition gave way, over much of the Rocky Mountain area, to a phase of more fine grained and more calcareous sedimentation. Hence, in very many sections, the top of the Lower Cambrian is marked either by a thin limestone or dolomite member (with a considerable sand content), or by an argillaceous and calcareous sequence. This member, or sequence, carries an abundant *Olenellus* fauna, and for many years was mapped as the base of the Mount Whyte formation. However, Burling realized as long ago as 1914 (1914, pp. 14, 20-23) that Walcott's Mount Whyte formation carries a Middle Cambrian trilobite fauna except in this basal portion, and that the boundary between the Lower and the Middle Cambrian should be drawn a good deal lower than Walcott was prepared to allow. The problem was finally settled by Rasetti (1951, pp. 53-64), who separated the *Olenellus-Bonnia* beds from the remainder of the Mount Whyte formation and referred to them as the Peyto limestone member of the St. Piran formation (Lower Cambrian). The overlying parts of Walcott's Mount Whyte formation (in some places the whole of it, as at Mount Assiniboine) are to be transferred to the Middle Cambrian, still under the same name. Both the Peyto limestone member and the Mount Whyte formation are extremely variable in thickness and in lithology. Furthermore, the faunas of the two sequences lie much closer together, stratigraphically, than evidence from elsewhere suggests they should; there are also some intervening faunas missing. It is therefore likely that there is a disconformity of some size at the top of the Peyto member. In the Bow Lake area, this member has a thickness of the order of 200 feet, but in the Bow Range it is commonly between 25 and 45 feet thick. Approaching the Stephen-Dennis fault, all the more fine-grained and thinly-bedded members thicken, at the expense of the quartzites and the dolomites, en route to becoming portions of the Chancellor formation. The Peyto limestone is no exception, and thickens greatly westward across the Bow Range. The equivalents in the Western Ranges, and presumably also beneath the Ottertail and Van Horne Ranges, form the lower part of the Eager formation. At Canal Flats, perhaps the lower half of this formation is of early Cambrian age—a few hundred feet. On Lussier River, the whole of it is Lower Cambrian (475 feet), and the Middle Cambrian is absent. The beds of the Eager formation are here a motley succession of shallow water sediments of varying bright colours; conglomerates, quartzites, sandstones, shales, and limestones are all represented. In the Cranbrook area, the Eager is enormously thick and just like the Chancellor formation. The *Olenellus* fauna is found near its base, but how much of the formation is of early Cambrian age is not known; in all probability, some few hundreds of feet.

Peyto to member of St Piran.

MIDDLE CAMBRIAN

Formations of medial Cambrian age were the most widespread of all in the early Palaeozoic of the Canadian Rocky Mountains. They represent the maximum lower Palaeozoic transgression eastward and southward, and contain the greatest variety of sediments. In the eastern portion of the Rocky Mountain province, they comprise a great series of massive carbonates, including true reefs, with some more thinly-bedded and shaly members; in the west, the proportion is about reversed and true carbonates are not much in evidence. This facies change from east to west is

the most pronounced in the entire lower Palaeozoic sequence, and may be likened to that taking place in the upper Devonian of the Prairies.

The greater part of the Cambrian succession remaining in the two front ranges belongs to the Middle Cambrian. The massive limestone immediately overlying the McConnell fault at Kananaskis appears to be the correlative of the Cathedral formation of the Main Range. The same applies to the remarkably pure white limestone which is quarried for the Loder Lime Plant, east of Exshaw. In each case, fossils have been found in thinly-bedded strata at the top of the limestone, and these fossils belong to the Stephen formation which overlies the Cathedral. There is thus no Upper Cambrian in the first range of the Bow River section. Another Stephen trilobite genus, *Ehmania,* has been reported by Beach (1943, p. 10) from his "Formation D" in the Moose Mountain area of the foothills. This would extend to this area the belt in which the Middle Cambrian is the youngest early Palaeozoic horizon present. "Formation C", occurring between the depths of 2764 and 3000 feet in the McColl-Frontenac well (see Beach, idem., p. 64) is also equivalent to some part of the Stephen formation. Formations "A" and "B" include a Cathedral equivalent, with probably the lower part of the overlying Stephen and the upper part of the underlying Mount Whyte.

In the Sawback Range, beds as old as Middle Cambrian are seldom seen, though the Eldon dolomite appears in the upturned ridges on the east side of the range, from Block Mountain northward to Red Deer River. Farther south, Middle Cambrian limestones form the east face of the main rib of the Royal Group. In order to find good and complete sections of beds of this age, however, it is necessary to move into the Main Range.

Here the general succession of Middle Cambrian formations was established on Mounts Eisenhower and Bosworth, and is as follows, with typical thicknesses:-

(Upper Cambrian above)

Pika formation	700 Feet
Eldon formation	1100 "
Stephen formation	450 "
Cathedral formation	1000 "
Mount Whyte formation	350 "

(Lower Cambrian below)

Total 3600 Feet

This succession would fit almost any mountain in the Bow Range or the Slate Mountains.

Northward along the Main Range, the formations below the Eldon thicken gradually; it is possible that this represents a regional southward thinning toward Montania. The total thickness of the Middle Cambrian formations increases about 500 feet between Mount Assiniboine and Bow Pass; it remains about constant between Bow Pass and Sunwapta Pass; and increases another 1000 feet or more between Sunwapta Pass and Mount Robson. There is a similar thickening in the Lower Cambrian between Mount Assiniboine and Bow Pass, but whether it continues into the Icefields is not known, since the whole Lower Cambrian goes below ground there. It is similarly difficult to know whether the Upper Cambrian thickens northward at all constantly, since, as will be demonstrated shortly, the facies change of the Eldon-Pika formations leaves us without a good marker horizon for the base of the Upper Cambrian in the North Saskatchewan River area.

The base of the Middle Cambrian is formed almost everywhere by a thinly-bedded limestone-shale unit, often with more or less sandstone and weathering to a reddish colour. This is the

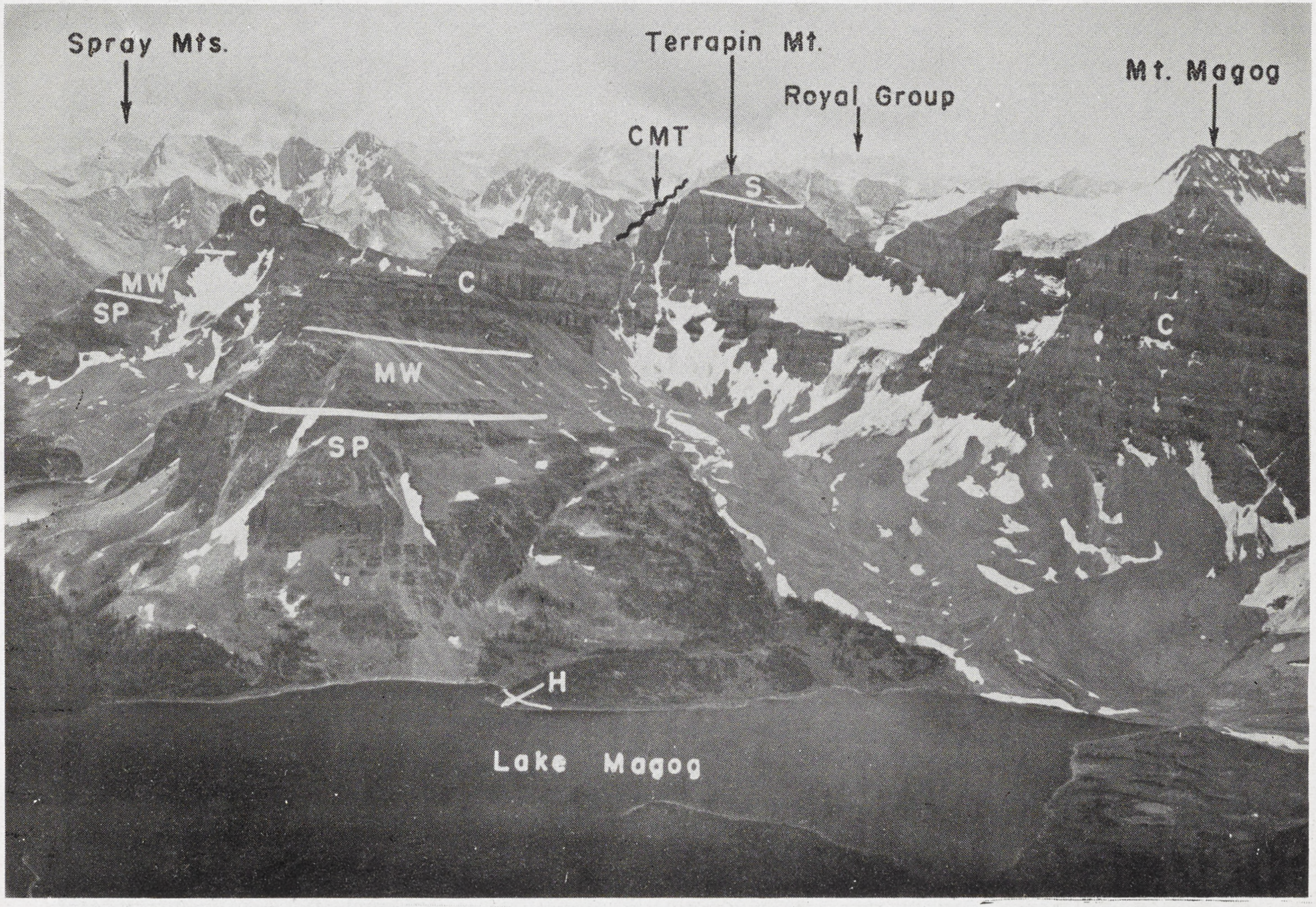


PLATE 13

Cambrian stratigraphy near Mount Assiniboine, and relationship of Castle Mountain thrust (CMT) to Assiniboine Massif. Trace of thrust passes immediately to left (east) of picture. S–Stephen; C–Cathedral; MW–Mount Whyte; SP–Saint Piran; H–Hector. Photograph by G. G. L. Henderson.

PLATE 14

The natural bridge over Kicking Horse River, west of Field, showing detail of Chancellor group beds. Bedding is gently undulatory, in places nearly horizontal. Prominent cleavage is nearly vertical. Photograph by M. K. Sorensen.

PLATE 15

Selective dolomitization producing thinly-bedded effect in Beaverfoot limestone. Pedley Pass section, in central fault block of Stanford Range. Photograph by F. K. North.

PLATE 16

Cliff exposing nearly 220 feet of pure gypsum of Siluro-Devonian age, on Kootenay River northeast of Canal Flats. Overlying talus probably covers more gypsum to a total thickness of nearly 750 feet. Photograph by F. K. North.

Mount Whyte formation, formerly regarded as the top of the Lower Cambrian but known to carry mid-Cambrian trilobites except at its very base (Peyto limestone member of Rasetti—see p. 53 of this paper). The distinctive genera are *Amecephalus, Plagiura,* and *Kochaspis.* Rasetti (1951, pp. 56-64) has given an excellent summary of the formation as seen in exposures in the vicinity of Lake Louise, showing that it thickens both eastward and westward from an axis of minimum thickness running about along the line from Cathedral Crags to Storm Mountain. Rasetti further describes two very fossiliferous shale lentils within the formation—the Lake Agnes and Yoho shale lentils.

The Mount Whyte formation can nearly always be picked out, unless it is extremely thin, since it is usually cut back into a narrow shoulder between the overlying Cathedral dolomite and underlying St. Piran quartzite. Its topographic expression is thus like that of the Stephen formation. In the Slate Mountains, it rests on the wide lower quartzite cliffs. It is seen on every mountain around Lake Louise (the type-locality is just west of the lake), but it is poorly exposed on Mount Bosworth. On the east face of Mount Stephen, it forms the banded sequence just below the mine entry. On the west face, where the overlying Cathedral formation is also a limestone-shale sequence, the Mount Whyte is not easily distinguished from it except by its fossils.

The Mount Whyte formation is overlain by the Cathedral, one of the great mountain-makers of the Palaeozoic succession. In its typical development in the Bow and Waputik Ranges, the Cathedral formation is largely a bedded dolomite with some limestone, but also containing lenses of pale reef-like dolomite (Plate 19). Several of these lenses are seen among the steeply-dipping beds of the formation on the lower north-east flank of Cathedral Mountain, cut through by the Kicking Horse River and highway. In its dominantly dolomitic development, the formation builds the central cliff along the face of Mount Eisenhower, much of the upper parts of the Slate and Bow Mountains (including the peaks of many of the mountains around Lake Louise), the north shoulder of Mount Stephen, the peak of Mount Burgess, and the whole main ridge of Mount Odaray. It also forms the wall on the east side of Yoho Valley, over which Takakkaw Falls cascade, and it is cut through by the lower spiral tunnel of the C.P.R. line. In this facies, the formation is poorly fossiliferous, but over part of the Bow Range there is a thin shaly member in the lower half (the Ross Lake shale), and this member usually carries the important *Albertella* fauna. Albertella

Both westward and eastward the formation undergoes major facies changes. Even within the Main Range, the changes from dolomite to limestone and back again are very rapid and irregular. In the western part of Mount Stephen, the massive carbonate facies of the formation gives way completely, and very abruptly, to a bedded succession of siliceous shales and argillaceous limestones, the change being similar to that affecting the Eldon on Park Mountain, to the southeast. Thus, on the lower slopes of Mount Stephen immediately east of Field, the Cathedral is indistinguishable lithologically from the overlying Stephen formation; on Park Mountain, the Stephen is similarly indistinguishable from the overlying Eldon. On Mount Burgess, however, which lies *west* of the Stephen-Dennis fault, both the Eldon and the Cathedral remain massive carbonate bodies. The present surface trace of the fault, therefore, does not quite coincide with the axis of major depositional transformation of the two formations.

Eastward, the Cathedral formation develops a more calcareous and less dolomitic facies. The lower parts were affected first, and in the Slate Mountains and on Mount Eisenhower the base is the dark, bedded limestone separated by Walcott as the Ptarmigan formation (see p. 47 of this paper). In the Front Ranges, as we have already seen, the whole formation is calcareous and non-dolomitic.

Rasetti shows Ptarmigan section to be Mt Whyte p 47

Back again to the Bow Range and vicinity, the Cathedral is overlain by the most fossiliferous formation of the whole Middle Cambrian succession, the Stephen. This much misunderstood

unit has been exhaustively treated by Rasetti (1951, pp. 70-79). It should be noted that its fossil zones extend over a much smaller footage interval than they do elsewhere (in Montana, for instance, or in the Great Basin area) in Cambrian sections otherwise thinner than our Rocky Mountain section. There are three possible explanations for this, and all have some evidence to support them: the Stephen may be a condensed deposit; it may carry within it one or more non-sequences; or it may carry several important fossil zones within a small stratigraphic interval because it occurs between two formations which represent unfavourable facies conditions for trilobite faunas. The lower part of the Stephen is characterized by several species of the genus *Glossopleura;* the upper part by the genera *Bathyuriscus* and *Zacanthoides.* It is in general a limestone-shale series, thinly-bedded and dark coloured, and its base often does mark a non-sequence following the deposition of the Cathedral formation. Where the Eldon and the Cathedral both have full carbonate development, as on Cathedral Mountain or Mount Eisenhower, their general appearance from a distance, with the Stephen between them, resembles that of the Rundle-Palliser cliffs of the front ranges, with the Banff formation between. The well-defined "shoulders" of Mounts Eisenhower and Stephen are cut back in the Stephen formation.

Both the Burgess shale and the *Ogygopsis* fossil beds appear to belong in the Stephen formation. However, as already pointed out (p. 30), neither is known except in minor fault-blocks between the Cathedral-Stephen and Stephen-Dennis faults. As both are local lentils of peculiar lithology, as well as peculiar fauna, neither can yet be reliably related to the normal succession, a fact which escaped Walcott's notice. Walcott believed he had established the position of the *Ogygopsis* beds within the Stephen formation of Mount Stephen, and he assumed that the Burgess shale, on the opposite side of Kicking Horse Valley, was their stratigraphic equivalent. However, the trail up the northwest flank of Mount Stephen, beginning behind Field, has a gradient lower than the west dip of the beds on that flank, which is in the footwall of the Stephen-Dennis fault. Consequently an ascent of the trail is a descent of the stratigraphic succession, which Walcott described upside-down. The fossil beds are faulted both above and below, and until they are found at some other locality their exact position in the sequence can only be guessed at from tenuous faunal relations.

The overlying Eldon is a great dolomite formation of which large parts bear an unmistakeably reefoid aspect—pale pink to buff or white in colour, unbedded, almost structureless, without fossils except for some algae, in many parts coarse, vuggy, hematitic, and petroliferous. It forms the upper crags of the front face of Mount Eisenhower and those fronting Cathedral Mountain. It is also the chief and thickest of the carbonate-bodies in the upper parts of Storm Mountain, Mount Bosworth, and Mount Stephen. On Mount Stephen, a beginning is made on its transformation to a shale-limestone sequence, with the appearance of a prominent band of dark siliceous shale, 150 feet thick, in the lower part of the formation. On Park Mountain, six miles to the southeast, the transformation is complete, the entire unit having given way to 1300 feet of siliceous shale and argillaceous limestone. West of the Stephen-Dennis fault, the equivalent is almost wholly argillaceous and forms part of the Chancellor group.

The reef-bearing Eldon appears to have developed along a submerged shelf joining two positive areas. The southerly positive area was Montania. The more northerly one lay in the general region of the headwaters of the North Saskatchewan River. Here the close of medial Cambrian time must have witnessed the development of an almost starved basin, the only beds there which can be equated with the combined Eldon and Pika being some thin lower portion of the Arctomys formation. This comparative failure of deposition in Eldon-Pika times was followed immediately by the submergence of the reef-growth to the south, and the deposition in the formerly starved area of the greatest known thickness of the next younger formation, the Arctomys (see p. 62). This, significantly, was a very shallow-water deposit, characterized by coloured shales and siliceous limestones with mud-cracks and casts of salt crystals. It is possible, therefore, that the brightly-coloured basal beds of the Arctomys originally contained evaporite

and were a lagoonal equivalent of the Eldon. Certainly the Arctomys is more than twice as thick where the Eldon is absent as it is when overlying reef-bearing Eldon. It is also of interest that the northern limit of reef-growth in the Eldon is almost in coincidence, as far as latitude is concerned, with that in the Fairholme south of the Saskatchewan River.

Pika

The upper part of the Eldon is more distinctly bedded, and the dolomite is much darker in colour. The Pika formation is simply a well-bedded dolomite-limestone sequence into which this portion of the Eldon merges upward. It was placed in the Upper Cambrian by its author (Deiss, 1939, pp. 1008-9), its base being then the Middle-Upper Cambrian boundary. However, it is difficult to map it separately from the Middle Cambrian, and it will be convenient, until the trilobite experts have come to a decision, to consider it as the youngest of the mid-Cambrian formations.

Eastward from the Bow Range, the whole Middle Cambrian becomes notably thinner—nearly 1200 feet thinner on Mount Eisenhower, for instance, than it is on Mount Bosworth. Southward, it is superbly exposed in the peaks of Storm Mountain, Stanley Peak, and Mount Ball, and it makes up two-thirds of the pyramid of Mount Assiniboine. In all these localities, both the Eldon and the Cathedral are of the dolomite facies.

Northwestward along the strike, and down the plunge, the Middle Cambrian drops to river level in the mountains south of the Saskatchewan crossing. Here, as already indicated, the Eldon formation is very thin or absent. Beyond Mount Coleman, the succession rises again and four Middle Cambrian formations are exposed on the great peaks rising above the Columbia Icefield. From Sunwapta Pass northward they make up the greater part of nearly every visible mountain, gradually rising as more and more of the underlying quartzites appear up the plunge. On the mountains surrounding Mount Robson, four Middle Cambrian formations are still distinguishable, their total thickness of about 5000 feet indicating a considerable thickening northwestward.

To the west of the Stephen-Dennis fault, the argillaceous facies quickly takes over the whole Middle Cambrian succession, which must lie wholly within the Chancellor group. In the Western Ranges sub-province, its distribution is much like that of the Lower Cambrian. Entirely concealed in the eastern and central fault-block of the Brisco and Stanford Ranges, it is known to be absent east of Fairmont Hot Springs in the western block. In this block, however, it appears east of the north end of Columbia Lake, as the upper part of the Eager (Burton) formation. At no point in this part of the range is it more than about 350 feet thick, and it is reduced to 60 feet at Elko. West of the Trench, and on the intravalley ridges within it, it again behaves much as does the Lower Cambrian, except that it is unknown in the Selkirks. In the Dogtooth Mountains, the Canyon Creek slates (Evans, 1933, p. 123) appear to represent part of the Chancellor group and may be wholly of Middle Cambrian age. They are at least 2000 feet thick; their base is cut off by a thrust-fault and their top may be faulted off also. On the intravalley ridges, and in the front of the Purcell Range, the Middle Cambrian is absent, presumably because of the presence of the positive area there which originated at the close of Windermere time (p. 52). Southward, beyond the limits of this upwarp, the shales and argillites again thicken toward Cranbrook. The Colville Embayment was still the site of considerable deposition at this period. The Metaline limestone, in the northeastern corner of Washington State, is of mid-Cambrian age and some 3000 feet thick. It is underlain by the Maitlen phyllite (Park & Cannon, op. cit.; Campbell, op cit.), which is like the Eager in lithology and further resembles it in having Lower Cambrian mesonacid trilobites in a limestone band at its base. Some upper part of the Maitlen formation is therefore very likely also of mid-Cambrian age.

Eastward from these southern areas, the mid-Cambrian seas still flanked Montania. Whereas this positive mass remained without sediment in the early Cambrian, it was submerged in the Middle Cambrian. Thus there are beds of that age lying on the Lewis overthrust sheet. The

sequence, never more than a few hundred feet thick in Canada, consists of a diachronic basal sandstone (the Flathead formation), followed by a very fossiliferous greenish shale (North, 1953, pp. 110-111). The shale is equivalent to some part of the combined Cathedral and Stephen formations of the Main Range, and to the Gordon shale of northwestern Montana. The great carbonate bodies of this period are not found again until we pass southward off the Montania block.

UPPER CAMBRIAN AND LOWER ORDOVICIAN

Formations of late Cambrian and early Ordovician age are less widespread in the Cordillera than those of the Middle Cambrian, except in parts of the Western Ranges. They are grouped together in this paper, since it is not known whereabouts in the Goodsir group to draw the Cambro-Ordovician boundary. In the Ottertail and Mitchell Ranges, the Cambrian part of the Goodsir may easily be 2000 or more feet thick. In the Main Range, it is certainly much less, usually less than 500 feet. It is equally uncertain where to divide the Upper from the Middle Cambrian, since the age of the Pika formation is not definitely established (p. 61). However, for mapping purposes the Pika is more easily included in the Middle Cambrian, and the overlying Arctomys formation provides a natural base for the Upper Cambrian succession. With the overlying Lower Ordovician, this is basically then as follows:—

3. Goodsir Group	Glenogle McKay Sabine	Sarbach Mons.
2. Ottertail formation	Lyell Sullivan	
1. Arctomys formation		

Allan's Sawback formation (1914, p. 172) equates exactly with this sequence, though there are probably non-sequences within it.

The Arctomys is characterized by thin beds and bright colours. It is dominated by shales, usually siliceous or calcareous and containing beds of limestone or dolomite or both. The shales are of all colours—maroon, red, yellow, and buff—and frequently bear mud-cracks and casts of salt crystals. They are thus the result of extreme shallowing of the depositional basin, possibly an enclosed one, following a period of reef-development (Eldon formation). As already indicated (p. 60) the more northerly of the Eldon reefs appear to have flanked a starved basin, or possibly a temporarily positive area, situated in the area now occupied by the Columbia Icefields. It was in this starved area that the younger Arctomys sediments were deposited most abundantly, and, as also already indicated, the lowest of them may be Eldon equivalents. Thus the Arctomys bears a relationship to the Eldon reefs somewhat akin to that of the Ireton to the Leduc reefs. The formation is now best seen around the lower slopes of the peaks in the Glacier Lake region, south of the Icefields. It thins northward and southward, and thickens for a short distance westward, from this central area. It forms the base of the Lynx formation on Mount Robson and neighbouring peaks. It is about 400 feet thick on the northwest slope of Mount Bosworth, and 270 feet in the cirque behind Mount Eisenhower. In the Bow Range and the Slate Mountains it was presumably deposited, though palaeogeological considerations suggest it must have been thin and probably of non-evaporitic facies; in these localities it is now everywhere eroded away. It has not been formally identified on Mount Assiniboine, but it presumably forms the prominent red band 1000 feet below the top of the mountain.

To the east, in the Sawback Range, the formation causes the similar red band at the base of the exposed succession on Mount Cory, and drops out of sight northward, down the plunge. In

the western sector of the Main Ranges sub-province, it is represented by the uppermost part of the Chancellor group and is probably responsible for the red colour of that part, well seen on the east face of the Van Horne Range. In the Western Ranges, the formation has never been identified, though the base of the Ottertail dolomite on Jubilee Mountain is reddish in colour and bears some resemblance to some of the sandy beds in the Arctomys.

The overlying Ottertail formation is the Canadian Cordilleran representative of one of the continent's great carbonate bodies. Apart from the interruption of Montania, which was very extensive in late Cambrian times, the great limestone-dolomite sequence was deposited continuously, from the Rocky Mountains of northeastern British Columbia, 1200 miles south-eastward at least into the southern corner of Nevada. It is variously known as the Lynx formation (in Mount Robson Park); Lyell plus Sullivan (Glacier Lake area); Ottertail (in the Ottertail Range); Jubilee (in the Western Ranges sub-province); Elko (in the Hughes Range); Pilgrim (in the Big Snowy Mountains of Montana, and the Three Forks-Logan District); Weeks limestone (in the type-section in the House Range, Utah); Hamburg dolomite (in central Nevada); and Mendha limestone (in the Highland Range, Nevada). In Walcott's type section at Mount Bosworth, the combined Bosworth, Paget, and Sherbrooke formations equate with the Sullivan or lower Ottertail. Of the formations listed here, the Lynx, Pilgrim, and Mendha, at least, include beds at the top and base which are younger and older, respectively, than the Ottertail formation. The Bosworth formation of the Kicking Horse Pass section may also go a little lower, stratigraphically, than the base of the Sullivan or of the Ottertail, but it is an unfossiliferous representative of the carbonate-rich facies and does not merit separate formational status.

The Ottertail is typically a massive, blue to gray dolomite or limestone, sometimes quite unbedded, averaging some 2000 feet thick, and poorly fossiliferous to barren. In Canada, it is marked by a general thinning southward towards Montania. It probably approaches 4000 feet in thickness on Mount Robson and neighbouring peaks, and exceeds 2400 feet on the mountains south of the Columbia Icefields(Mount Lyell, Mount Outram). There is no complete section anywhere in the Bow Range or vicinity, where erosion has removed most or all of the formation. The lower parts (the so-called Bosworth limestone) form Stuart Knob behind Mount Eisenhower, and Paget Peak northwest of Mount Bosworth; they also cap Mount Stephen, and make up the top 1000 feet or so of the pyramid of Mount Assiniboine. The upper parts of the formation form the central rib of the steeply tilted part of the Sawback Range over much of its length north of Bow River; the top is marked, in several localities, by huge colonies of a giant alga, *Collenia prolifica* (Walcott, 1928, pp. 294-6, pl. 56, 57).

The most complete and perfect exposures of the formation are along the precipitous "Rock Wall" on the east face of the Ottertail Range (Frontispiece). They begin with Mount Hurd, northeast of Leanchoil, and run southeastward along the west side of the Ottertail-Vermilion valley and down the plunge, dropping below valley level in the region of the transverse section of Cross River. The best exposures of the entire formation to be seen from the Banff-Golden highway are on the west faces of Mount Vaux and Chancellor Peak, where the formation is about 2000 feet thick. The Banff-Windermere highway cuts through the same range five miles northeast of Kootenay Crossing, and Mount Verendrye, Foster Peak, and Mount Gray are high peaks in the range visible from the road. This whole belt is underlain by a major thrust fault, the rocks in the immediate hanging wall being heavily sheared (see pp. 31, 32). The Ottertail formation passes down-plunge into the sheared zone and is marmorized at Marble Canyon.

In the Western Ranges, where it is known as the Jubilee formation, the unit consists almost entirely of dolomite. It is not seen at Golden, since the most westerly range of all (west of the Redwall fault) is the only one to expose it and this range has entered the Trench farther to the south. On the east side of the Trench it is first seen, going south, in a fault-sliver at Radium Hot Springs; it is, in fact, the horizon from which the springs emanate. Southward from Stoddart

Creek to Canal Flats it is the dominant ridge builder along the west face of the Stanford Range. It is about 1800 feet thick east of Windermere, and 1500 feet at Canal Flats, thence thinning rapidly southward until it is last seen north of Elko, less than 100 feet thick between the Devonian and the Middle Cambrian on the northwest flank of old Montania.

On the west side of the Trench, and on the two ridges within it, the formation behaves in exactly the opposite manner to the Lower Cambrian quartzites. It is not seen in the Dogtooth Mountains, where the quartzites are very thick; it achieves about its maximum thickness for the southern ranges (2000 feet) on Jubilee and Steamboat Mountains, where the quartzites are absent. The failure of the formation to appear in the Dogtooths is difficult to explain on grounds of non-deposition. It seems more likely that it has been faulted out by an unmapped fault east of the band of the Canyon Creek slates. Across the Trench it thins rapidly to 300 feet on Horsethief Creek, resting on the Precambrian Windermere series, and thence westward it presumably wedged out altogether.

Upper Ottertail = Lyell
Lower Ottertail = Sullivan

Lithologically, the unit varies little throughout the southern Rocky Mountains, except for the degree of dolomitization. The upper half is heavily-bedded to unbedded, and unfossiliferous; this is the Lyell formation of Walcott. The lower half (Walcott's Sullivan formation) is well-bedded to laminated, and, going northward down the plunge of the Main Range, this portion contains an increasing proportion of interbedded greenish shale. The lower portion is also increasingly fossiliferous northward, since the shale members carry a well preserved Dresbachian trilobite fauna. The most distinctive genera are *Blountia, Bynumia, Kingstonia,* and *Arapahoia.* Tracery by chert is a common feature in both upper and lower portions.

Following the Ottertail is the Goodsir formation, more properly to be called the Goodsir group. Allan's estimate of its thickness, on Mount Goodsir, was 6040 feet, top not seen. This huge thickness was originally placed entirely in the Ordovician, but the base is certainly Cambrian, and the Cambro-Ordovician boundary may be 2000 feet or more above the base. Unfortunately, the bulk of the group is unfossiliferous, only the lower 300 feet of the type-section having yielded a reliably identifiable fauna. The age of this fauna is that of the *Elvinia* zone (basal Franconian).

The group is characterized by thin bedding, which on differential weathering appears as prominent banding or striping. Though less than half the rock in the group is true shale, the group as a whole is notably less resistant to weathering than the older Ottertail or the younger Beaverfoot and Brisco formations.

The greatest development of this thinly-bedded series coincides with that of the argillaceous facies of the Middle Cambrian—in the western sector of the Main Ranges sub-province, and in the Western Ranges. In the former, it occurs on nearly every mountain along the Ottertail Range, and makes up most of Hawk Ridge, across the Vermilion valley. It becomes completely dominant southward, down the plunge, and occupies practically the whole width of the southern Mitchell Range, between Cross and White Rivers. The group in the Ottertail Range is of the cherty facies—banded cherts and cherty limestones, siliceous shales and calcareous shales, very poorly fossiliferous. Deposition of this sequence began rather earlier than that of the "Goodsir group" elsewhere, so that the fossils at its base are older than any known in other sections of the group.

In the Western Ranges, where it is known as the McKay group, it is the thickest single series represented and areally the most widespread in outcrop. Unfortunately, no complete section is known, and few unfaulted ones, but its greatest thickness is probably more than 5000 feet. McKay group rocks are the oldest seen in the eastern block of the Brisco and Stanford Ranges, merging eastward into the schist-zone of the White River Break. In the central block of the ranges are found the thickest and most complete sections of the group; over 4000 feet are exposed

east of Fairmont Hot Springs, and some 4500 feet at the type locality on John McKay Creek, east of Radium. The facies here is quite different from that in the Ottertail Range, with much less chert and rather less shale, much more bluish limestone and even some dolomite. In the centre of the succession there is a notable proportion of intraformational limestone conglomerate. Moreover, the facies here is in parts fairly fossiliferous, the faunas extending in age from mid-late Cambrian to late Chazy (Evans, 1933, pp. 127-129). In the western fault-block of the Stanford Range, the group has a distribution similar to that of the Jubilee (Ottertail) below it, though the changes in thickness are more abrupt. More than 3000 feet are exposed east of Athalmer, where the top was apparently eroded before the Beaverfoot limestones followed. A very abrupt southward thinning leaves only about 100 feet of the basal portion of the group south-east of Windermere, and this has been reduced almost to zero five miles farther south. At this latter point, the group provides strong confirmatory evidence for transcurrent movement along the Redwall fault. On the east side of the fault, immediately opposite the point at which the McKay has pinched out to nothing, it is at least 4000 feet thick.

In some of the more complete sections of the group in the Western Ranges, the series passes down into a blue-grey, crystalline limestone, which is much younger than the youngest Jubilee (Ottertail) which should underlie the McKay. This member carries the fauna of the *Briscoia* zone, and is part of the Sabine formation of Schofield (1921, p. 76). Southward along the western fault-block of the range, the entire Sabine formation is exposed, the greater part of it consisting of rusty-weathering, thinly-bedded limestones and shales. The fauna of this part of the formation belongs to the *Prosaukia* zone, slightly older than the *Briscoia* zone. This portion first appears east of Fairmont Hot Springs, and thickens southward, being 200 feet thick east of the north end of Columbia Lake, and 700 feet thick east of Canal Flats.

The greater part of the Rocky Mountain Trench between Donald and Windermere appears to be underlain by badly shattered and mashed McKay group strata. Relatively unsheared beds of the whole formation are represented on the two intravalley ridges, about 2000 feet thick in each case. Only the very base is seen below the Dogtooth Mountains, over-ridden by the frontal fault of that range. Southward along the west side of the Trench, the group has wedged out to nothing shortly south of Horsethief Creek.

In the eastern sector of the Main Ranges sub-province, the Goodsir group first appears, going northward down the plunge, a little north of Bow Pass. It forms most of the lower slopes of Mounts Murchison, Wilson and Sarbach, immediately south and north of the crossing of the Saskatchewan River. In this general area, the group was divided into two formations by Walcott —the Sarbach above, the Mons below—on the grounds that the latter belonged in the "Ozarkian" of Ulrich and should not therefore be associated with strata carrying a true Ordovician fauna. As few geologists now use an Ozarkian system, and as both Walcott's formations are much alike lithologically, except in the Sawback Range, it is convenient for the field geologist to consider them within the single group. The thinly-bedded, putty-gray series of argillaceous and siliceous limestones and shales is always easy to pick out, appearing with sharp contact above the massive Ottertail (Lyell) dolomite and being overlain equally sharply by the Mount Wilson quartzite (or even more sharply, where the quartzite is absent, by the Fairholme). As the area of maximum thickness for the group has been seen to lie astride the 51st parallel, the sections north of Bow Pass thin rapidly northward. At the headwaters of the North Saskatchewan River, the group is about 2000 feet thick; here the lower part resembles parts of the McKay group of the Western Ranges in containing a good deal of intraformational limestone conglomerate. At Sunwapta Pass the thickness is about 750 feet, and the facies is cherty, like that on Mount Goodsir. Up the plunge again, the group is largely eroded away from the Jasper area, but its lower portions may be represented by the Chushina formation of Mount Robson and vicinity, where intraformational conglomerates are also common.

Altoba
Clearwater

In the Front Ranges, the distribution of the Goodsir group is probably much like that of the underlying Ottertail, except that more of it, naturally, is now seen. As far as is known, it is completely absent in the first two ranges. Whether this is due to non-deposition or to erosion is difficult to decide, but we incline towards the former belief. In the Sawback Range, however, the group is splendidly exposed, at least north of Bow River. Immediately east of the Castle Mountain thrust the group crops out below the Devonian and forms the lower parts of the range from Baker Creek northward to Siffleur River. A splendid section forms the east slopes of Fossil Mountain, immediately south-east of the Skoki ski lodge. In the central part of the northern Sawback block, where the beds are less steeply dipping, the group forms the lower eastern scarp faces of all the main mountains north of Sawback Lake (Bonnet Mountain, Mounts St. Bride and Douglas, Cyclone Mountain). To the north, it crops out at the base of the Palisades at Jasper. To the south, it immediately underlies the thrust on Johnston Creek, east of Mount Eisenhower, and west of Banff it makes up the shaly series between the ribs of Devonian and Ottertail, east of the Hole-in-the-Wall. Still farther south, it is probably the chief horizon represented in the lower western slopes of the Royal Group.

Throughout the Sawback Range the group is readily divisible into Walcott's two formations, Sarbach and Mons, since the former consists here of a fairly thickly bedded limestone with some dolomite and chert, whereas the Mons is the typical putty-gray, thinly-bedded limestone and shale. Each part is of the order of 800 to 1000 feet thick in the region of Pipestone Pass, but southward the top is progressively truncated by the transgressive Devonian. This is an illustration, *along* the strike, of what must also have happened *across* it, since in the first range at this latitude the Devonian rests on the Middle Cambrian and the Goodsir group is cut out altogether.

Glenogle

In some areas where the Goodsir group is dominated by shaly beds, there is a major development in its upper part of black graptolitic shales. These have been separated at the formational level as the Glenogle formation, and they are easy to map as such, but nonetheless their occurrence supplants some other portion of the McKay (Goodsir) group, in most cases part or all of the Sarbach (Beekmantown-Chazy) portion of it. The black shales reach their full development, so far as is known, in only three areas: in the eastern and central fault-blocks of the Brisco, Stanford, and Hughes Ranges; in the southern extension of the Mitchell Range, on White River; and in the Metaline Falls area of northeastern Washington. In the latter area they are known as the Ledbetter Slate, and reach a thickness of some 2500 feet, crossing over into Canada south of Nelson. The best development known in Canada extends in a belt from Moberly Peak, north of Golden, south-eastward along the eastern and central fault-blocks of the Brisco and Stanford Ranges and into the northeastern part of the Hughes Range. As would be expected from their mode of occurrence, the black shales are very erratic in thickness. North-east and south-east of Golden they are 1600 feet thick or more. At Luxor Pass, in the main Brisco syncline five miles south-west of Kootenay Crossing, they are also 1500 feet thick, but are reduced to 100 feet two miles farther west, on Pinnacle Creek. On the east slopes of Mount Sinclair, they are 1600 feet thick, but on John McKay Creek, north-east of Radium, they are absent. Their greatest thicknesses are found in the eastern fault-block of the Stanford Range, between the headwaters of Shuswap and Windermere Creeks. Here they are between 2000 and 2500 feet thick, which is thicker than the entire McKay group in some areas not far distant. On the other side of the Stanford fault, however, the thickness is reduced enormously (in one case from 2500 feet to about 400 feet); it is reduced still further upon crossing the central fault-block to its western side, at which position the Glenogle has at almost all points wedged out to nothing. At no point is it known to occur west of the Redwall fault.

The upper parts of the Glenogle, where properly developed, grade upward through an increase of thin quartzite members into the next younger formation, the Wonah. The Wonah,

however, is mapped more easily with the Beaverfoot than with the Glenogle, and will therefore be described in the next section.

UPPER ORDOVICIAN AND LOWER SILURIAN

The beds to be considered in this section form a natural mapping group, as McConnell realized when he united them as the "Halysites beds." They are now broken down into three formations, thus:—

3. Brisco formation (Silurian: Alexandrian and Clintonian)
2. Beaverfoot formation (Ordovician: possibly all Richmondian)
1. Wonah formation (Ordovician: probably post-Chazyan, pre-Richmondian)

The Wonah is a clean, thickly-bedded, white quartzite. The Beaverfoot and Brisco formations are both mountain forming dolomite-limestone sequences, inseparable except on a faunal basis. In this paper, therefore, we shall follow the precedent by Walker (1926, p. 31) and continued by Evans, and write of the "Beaverfoot-Brisco" as if only a single formation were present.

The whole sequence belongs essentially to the Western Ranges sub-province, though individual parts of it are known to occur in both sectors of the Main Ranges sub-province, and in the Front Ranges sub-province. In the Western Ranges, the quartzite and the dolomite are closely associated along the whole length of the Brisco syncline, and on the west face of the Van Horne Range, east of Golden.

Western Ranges

In the latter area, the Wonah reaches a thickness of about 1000 feet. Where the main rib of the Brisco syncline enters the Trench, six miles south-east of Golden, the quartzite has thickened to its maximum of about 1500 feet; thereafter it thins erratically south-eastward, and very rapidly and markedly south-westward. It is 1000 feet thick east of Harrogate. At Luxor Creek, it is 200 feet thick in the eastern and 30 feet thick in the central fault block. At Sinclair Creek, the equivalent figures are 400 feet and 60 feet; at Shuswap Creek, 450 feet and 20 feet; at Tegart Pass, 170 feet and 40 feet. South of Mount Tegart, in the central block, the formation is 100 feet thick on the east limb, and zero on the west limb, of a single fold. It is nowhere known to extend into the western fault block of the range, nor across the Trench, nor southward beyond a point about 8 miles south of Whiteswan Lake.

The Beaverfoot-Brisco in the Western Ranges extends in age from Richmond to Clinton inclusively, and occurs in fine development in all three fault blocks of the Brisco and Stanford Ranges. Over much of the ranges, it is the youngest formation remaining. In its maximum development, in the southern part of the central fault block, it is over 2000 feet thick. Since it carries the present erosion surface at many places, the average thickness is difficult to estimate, but it is over 1500 feet. There is a slight eastward thinning towards the White River Break, and a very strong westward thinning across the Trench, as evidenced by two occurrences of the formation on opposite sides of Horsethief Creek (Walker, 1926, pp. 32-34).

The typical rock of the undivided Beaverfoot-Brisco is a gray to pinkish dolomite, massive to well-bedded, with a good deal of chert in places. Some members are extremely fossiliferous, with solitary and colonial corals (usually silicified), brachiopods, gastropods, and enormous orthocerate cephalopods. The upper few hundred feet of some sections contain lenses of dark brown, fissile shale, with uniserial graptolites of Clinton age. The best outcrops of the formation to be seen from the highway are those on Mount Sinclair and along the west face of the Brisco Range between Harrogate and Radium Junction.

The distribution of the Wonah and Beaverfoot-Brisco formations in the Main and Front Ranges sub-provinces is poorly known. In the former, the beds crop out in synclines in the

southern part of the Mitchell Range, first appearing about the latitude of Whiteswan Lake. Farther north in the western sector of the sub-province, any beds of this age ever deposited have been eroded away. In the eastern sector, the plunge is in the opposite direction, so that formations as young as these occur only within the frontal syncline in the pitch-depression. Within the syncline, the quartzite (here known as the Mount Wilson formation) extends only from Wilcox Pass in the north to Pipestone Pass in the south. From zero at each of these points, it thickens to a maximum of about 550 feet at Mount Wilson. The overlying "*Halysites* beds" occupy a still smaller area immediately around Mount Coleman, their maximum thickness here being about 150 feet.

The presence of the formations in the Front Ranges, like that in the eastern sector of the Main Range and unlike that in the western sector, does not depend upon the plunge. In the first two ranges of the Bow River section, both the Wonah and the Beaverfoot-Brisco are certainly absent; nor are they known to appear anywhere along the strike in these ranges. In the third range at this latitude, the Wonah may be represented by the dolomitic quartzite at the very base of Sulphur Mountain, but this is not certain. In the Sawback fault block, the distribution of the Wonah is fairly clear; that of the Beaverfoot-Brisco rather less so. The Wonah (or Mount Wilson, if we are to be rigid about nomenclature) is present, in the mountains immediately east of the Castle Mountain thrust, from Brazeau River to Pipestone Pass. It is absent from Pipestone Pass to the Bourgeau Range, over which interval Devonian rests on Goodsir. It may reappear south of Kananaskis Lakes, but has not been certainly identified. The Beaverfoot is certainly absent from the Sawback belt from the Red Deer River to the Bourgeau Range. It may, indeed, be absent throughout the Sawback Range north of Bow River and its northward extension. However, Walcott (1928, pp. 329-330) described a section of the Sarbach formation from the south side of Clearwater canyon, opposite Mount Willingdon. The upper part of this section, totalling 762 feet according to Walcott's figures, appears from the description totally unlike anything found elsewhere in the upper part of the McKay group. We have not seen the section, but until it is adequately studied we think it may include a Beaverfoot equivalent. The absence of trilobites, and the presence of abundant coiled gastropods, with orthocerates and sponges, certainly suggests Beaverfoot rather than McKay age. Moreover, the section is said to overlie a graptolite-bearing member. In the Sawback fault block south of Bow River, the Beaverfoot formation appears for the first time on the west face of the Spray Mountains and continues southward as far as White River. The Brisco, or Silurian portion, is not known anywhere in the Front Ranges.

As a generalization, the Beaverfoot portion of the formation is the equivalent of the Stony Mountain formation of Manitoba and of the Bighorn dolomite of Wyoming and eastern Montana. According to Dr. Alice Wilson, however, the Beaverfoot faunas differ sufficiently from those of the formations farther east to indicate a measure of faunal isolation in the west (1926, pp. 1-4). That this isolated fauna extended over a considerable belt, however, is shown by the fact that it is known in the Rocky Mountains of north-eastern British Columbia, north of Peace River. This unexpected alliance, between the Western Ranges of our present area and the Canadian north-west, is even more strikingly illustrated in the case of the Middle Devonian formations.

UPPER SILURIAN AND/OR MIDDLE DEVONIAN

In a few localities west of the White River Break, the Beaverfoot-Brisco formations are overlain, apparently conformably, by a most variable succession of limestones, coloured shales, quartzites, dolomite, or gypsum. North of Sinclair Creek, in the Brisco Range, only limestones and quartzites are represented, and they comprise the Harrogate formation. The top is extraordinarily fossiliferous, especially in small brachiopods, and this portion is certainly of Middle Devonian age. At a number of places in the Stanford Range, the same fossils occur again,

apparently in the same rubbly, nodular limestones. Instead of the barren limestones and quartzites below, however, the upper Harrogate beds of the Stanford Range are underlain by a thick gypsum formation. This has been named the Burnais formation by Henderson (1954).

On the west side of the Rocky Mountain Trench, at a single locality north of Horsethief Creek, the upper Harrogate fossils occur again, in Walker's Starbird formation (1926, p. 35). At this locality, their horizon is underlain by neither limestone, quartzite, nor gypsum, but by a sequence dominated by red and green dolomitic shales (the Mount Forster formation). These shales are also seen in one locality east of the Trench, on Kootenay River north-east of Canal Flats.

A reasonable inference seems to be that the lower part of the Harrogate formation, and the Mount Forster formation, are stratigraphically equivalent to one another and to the Burnais gypsum. The best exposures of the Harrogate formation proper are within the isoclinally folded Brisco syncline, where it is the youngest horizon left. It is our opinion that it was the youngest ever to be deposited there. The Mount Forster formation is not known except in the two localities already mentioned. Both formations are of the order of 800 feet thick.

The gypsum occurs in a number of scattered areas in the Stanford and Hughes Ranges, and also extends a short distance west of the southern portion of the Rocky Mountain Trench. It is not known north of Sinclair Creek, nor east of the White River Break, nor south of the 49th parallel. Most of the occurrences, including all those easily accessible from the highway between Cranbrook and Wardner, and the very large one north-east of Canal Flats (Plate 16), are in down-faulted blocks surrounded by much older rocks. The best continuous succession shows the probable thickness of the gypsum to be at least 700 feet, and its age post-Clinton, pre-Pine Point. The fauna of the overlying upper Harrogate beds is largely that of the Middle Devonian of the Canadian northwest. This suggests some alliance, in age, between the Burnais gypsum and that of the Fitzgerald formation, and is a further striking parallel between the mid-Palaeozoic successions west of the Kootenay valley and north of the Peace River.

One of our major tectonic conclusions, put forward in the final chapter of this paper, hinges partly on the belief that the Burnais gypsum of the Stanford Range is of primary origin and is not secondary after anhydrite. The evidence for this is the absence of anhydrite, of expansion structures, or of distortion of paper-thin primary lamellae within the pure gypsum. The gypsum now occurring within the Hughes and eastern Purcell Ranges is not primary; moreover, there is no proof that it is of the same age as the gypsum in the Stanford Range. However, unless and until proof to the contrary is forthcoming, it must be considered that all the gypsum is of the same age. That in the south has passed through at least one anhydrite phase because of burial beneath younger Palaeozoic rocks in the long-subsiding prototype of the Fernie Basin.

UPPER DEVONIAN AND CARBONIFEROUS

Formations of late Devonian, Mississippian, and probable Pennsylvanian ages are perhaps better known than any others in the Palaeozoic of the Rocky Mountains, especially to the geologists of oil companies. They are not treated in detail in this paper. Instead, a bare outline is given of their distribution in the various sub-provinces.

Rocks of the three periods are commonly represented together, and are characteristic of the Front Ranges sub-province. The general succession of Rocky Mountain-Rundle-Banff-Exshaw-Palliser-Fairholme-Ghost River is recognizable practically everywhere along the length of this sub-province from Clearwater River to the Highwood. Southward and southwestward from the latter, we enter the prototype of the Fernie Basin, which originated as a strongly subsiding basin in late mid-Devonian time. The Upper Devonian within it is of a more clastic facies than the Fairholme-Palliser sequence, and this facies extends over the whole Crowsnest-Fernie Basin area.

The Mississippian is very much thicker in the proto-basin than elsewhere, and extends from it southward along what is now the Macdonald Range. It also doubtless underlies much of the Flathead Valley. The proto-basin also allowed what was probably the only extension of late Devonian and Mississippian sediments westward of the present position of the White River Break; they are seen now in the western part of the embayment, along Bull River, northward almost to Whiteswan Lake and southward along both sides of the Kootenay Valley, beyond Wardner. It is to be doubted whether Devonian sediments were ever deposited far to the west of the Rocky Mountain Trench. The Carboniferous, however, is very widely distributed in the Interior systems, and is there of a facies utterly different from that in the Rocky Mountains.

The late Devonian-Mississippian transgression was sufficient to overcome Montania, just as in the north it finally eliminated the Peace River "high" as an emergent element. Consequently both Upper Devonian and Mississippian formations are preserved in down faulted blocks within and on the flanks of the Galton Range; the Devonian is also left as erosional remnants overlying the Beltian of the Lewis overthrust, where any Mississippian deposited has been eroded away. In the Montania sector both the Upper Devonian and the Mississippian are of the Montana facies.

Flume-age and younger beds were probably deposited all over the Main Ranges sub-province, but they are now seen only in the pitch-depression of the eastern sector of the sub-province. The Fairholme and Palliser carbonate bodies cap the mountains between the Freshfield and Columbia Icefields, and over the equivalent stretch east of the Banff-Jasper highway. The very highest peaks in this interval (Mounts Murchison, Forbes, Chephren) are capped by Mississippian limestones, the equivalent of the Rundle formation of the southern sections. If beds as young as these were ever deposited in the western sector of the sub-province, they have long since been eroded away.

POST-LARAMIDE, PRE-PLEISTOCENE DRAINAGE

It is not the purpose of this paper to discuss geomorphic data. However, it is probable that there is a good deal to be learned of the structural history of the Rockies by careful physiographic studies, allied to the study of aerial photographs. One fascinating aspect involves the apparent reversal of drainage, on an enormous scale, throughout much of the southern Rockies, the Purcells, and the Selkirks. The classic exposition of this is by Douglas Lay (1940-41), for the Fraser River, but equally striking reversals have affected the other large longitudinally-flowing rivers at various times. Some of the reversals must have been brought about by the Laramide revolution. Others appear to be the result of captures in post-Laramide, pre-Pleistocene times; one such is the southward diversion of the Bow River, via the elbow of capture at Bow Falls and across the rib of the Rundle Range. Yet other reversals were brought about by ice-interference during the glacial period; the westward diversion of the Kicking Horse, across the Beaverfoot Range, may date from this period.

In general, the drainage during Tertiary times must have been largely southward and eastward from the southern Rockies. The two main limbs of the southward drainage system we may call the Proto-Columbia River and the Proto- Kootenay. The latter was at that time wholly an interior system river, having its headwaters in the Glacier Park area (centering on Mount Sir Donald) and flowing almost due south via Pend'Oreille Lake. The Proto-Columbia and its tributaries were responsible for the whole southward drainage of the mountain area east of the Rocky Mountain Trench. The main trunk appears to have had its headwaters about in the Blackwater Range, northwest of Donald, and to have flowed southward along the whole length of the Trench to Flathead Lake, and thence probably southeastward into the Missouri drainage system. The main southward run-off from the area of the southern Rockies was brought into

this trunk stream by two tributaries, the Proto-Kicking-Horse and Proto-Elk Rivers. The former rose in the vicinity of the Waputik Icefield, and flowed via the present Yoho and upper Kicking Horse valleys into what is now the valley of the Beaverfoot and the upper Kootenay. It flowed southward down this valley, and thence via that of the present Lussier River to join the Proto-Columbia. The Proto- Elk had its origin in the vicinity of Banff, flowing southeastward along the valley now occupied by the Spray and so into the modern Elk Valley.

Thus the original southward drainage has suffered diversion and reversal on a considerable scale. Most of the present master streams originating from this system turn back on themselves at least once in their courses, forming the so-called "Big Bends." They are also characterized by splendid examples of elbows of capture, the best being at Wapta Falls on the Kicking Horse. Conversely, the captured or foreshortened streams have ponded headwaters in practically all cases. The best example of this is at Kananaskis Lakes, forming the present watershed between the foreshortened Elk River and the captured Spray.

The major eastward drainage of Tertiary time has not, of course, suffered reversal, but a good deal of foreshortening has taken place as a result of captures. The three main trunk streams must have been largely as they are today—the Athabasca, Saskatchewan, and Bow Rivers. The Athabasca originally headed in the Columbia and Hooker Icefields. The Saskatchewan, likewise, drained an icefield of which the Freshfield and Wapta glaciers are remnants. Its headwaters have been captured by the west-flowing Blaeberry River; those of its main tributary, which headed in the vicinity of Hector Lake, have similarly been captured by the south-flowing Bow. The original Bow must have headed about at Lake Louise, and have extended itself headward along the strike of the great anticline in the eastern sector of the Main Ranges sub-province. In its lower course, the pre-Pliocene Bow apparently followed the valleys now occupied by Lake Minnewanka and the Ghost River. By some means (thought by Allan to be damming by the gravels brought down by Fortymile Creek), the river was forced out of this channel and acquired a new one by capturing the headwaters of the Spray or Proto-Elk River.

STRUCTURAL AND STRATIGRAPHIC SUMMARY & CONCLUSIONS

We wrote at the beginning of this paper that there are some readily apparent features of the Canadian Rocky Mountains which require more explanation than has so far been forthcoming. The chapters just completed have brought attention to some of these features, some of the geological evidence bearing upon them, and some suggestions to account for them. Before attempting to reconstruct the structural and stratigraphic history of the mountains, let us remind ourselves of the major questions for which answers have to be found. We have so far considered the structure before the stratigraphy, because, as we wrote, the real complication is in the structure. However, the structure cannot be understood properly until the chief stratigraphic problems have been solved. We shall now, therefore, consider these first, and the structural problems afterwards.

Stratigraphic Problems

1. All geological chronologists appear to be agreed that the Cambrian period was of longer duration than any subsequent period. If, during this period, a true geosyncline occupied the site of the present Southern Rocky Mountains, why did it accumulate only 10,000 feet of Cambrian sediments? And why were these sediments so predominantly calcareous? The total thickness of the sedimentary body of some ten formations is easily surpassed by that of a singe formation in any typical Flysch. The Purcell series of eastern British Columbia, the Franciscan of California, the Miocene and Pliocene sands of many areas of Tertiary downbuckling, are each from three to five times as thick as the Cordilleran Cambrian.

2. Why are there, apparently, no formations between the Lower Cambrian and the Carbo-Permian in the Selkirk area and westward from it?

3. Why are there so many stratigraphic gaps in the Rocky Mountain succession, especially above the Lower Ordovician?

4. Why is the Western Ranges sub-province provided with a thick sequence of formations, in age ranging from late Cambrian to mid-Devonian inclusively, equating almost exactly with the sequence which is *missing* in the first two or three Front Ranges at the same latitudes? And why was sedimentation apparently resumed in the Front Ranges area when it finished in that of the Western Ranges?

5. What is the Chancellor "formation," and why does it not exist in the Main Range?

6. Why does a very shallow water deposit, the Arctomys, have the thickness and distribution it does have, as part of such a continuous Cambrian sequence?

7. What is the significance, if any, of what is probably the world's thickest deposit of pure gypsum, apparently primary?

Structural Problems

1. The depositional environment of the Precambrian and early Palaeozoic sediments of the Rocky Mountain province is usually regarded as having been that of a true geosyncline—not merely in the very wide sense adopted by Marshall Kay and others, but also in the original and much stricter sense used by Dana and Schuchert. If this is so, why was the geosyncline not deformed until the early Tertiary? All other known Palaeozoic geosynclines were deformed during the Hercynian and Appalachian revolutions if they had escaped earlier ones.

2. What is the explanation of the lack of serious deformation in the eastern sector of the Main Ranges sub-province and overlying the great salient of the Lewis overthrust, in spite of these tracts being composed of very old rocks at very high elevations?

3. Why is the (apparently) only lightly disturbed Ottertail-Mitchell belt distinguished by a remarkable zone of intense shearing if the structure across the belt is that of a simple monocline? (Allan, 1914, p. 197; Evans, 1933, p. 163).

4. How did beds of a single formation, but of different facies, come to be brought into juxtaposition on two sides of a shear-zone, along the Beaverfoot, Kootenay, and White Rivers, although the beds on the two sides are overturned in opposite directions?

5. If the thrust faults mapped among the Front Ranges are actually discontinuous and separate structural features, as they are always represented to be, why do they bring beds of the same age, and the same facies, to about the same elevation in each of the three front ranges; and why do all three ranges plunge almost uninterruptedly in the same direction? The fault-blocks in the Main Range have no such uniformity. And what are the *relative* importances of the six or seven major westerly-dipping thrusts between the front of the Main Range and that of the foothills?

6. How can all the peculiar phenomena associated with the Rocky Mountain Trench be accounted for? In particular, how does it come to be able to truncate both the Interior system structures to the west of it and the Rocky Mountain structures east of it?

7. Is it possible to make any worthwhile estimate of the amount of crustal shortening which the rocks now exposed in the Rocky Mountains have suffered?

Many other similar problems will present themselves to anyone who has worked in the mountains; even, possibly, to anyone who has only read this paper. Those listed here, however,

appear to us to be the crucial ones on our present knowledge. If and when answers can be found for them (answers which must be consistent among themselves), we shall be somewhat nearer to an understanding of Rocky Mountain genesis than we are now. The remainder of this paper will be devoted to an attempt to formulate an "outline of history" of the southern Canadian Rockies which will take these problems into account. The conclusions we offer seem reasonable, to us, on the facts already known. In the gathering of facts, however, we have no more than scratched the surface.

Depositional History

It is our belief that there was no lower Palaeozoic geosyncline, in the strict meaning of Dana or Schuchert, on the site of the southern Canadian Rocky Mountains. There was a true geosyncline, farther west, in Purcell times; but this was partly deformed between the Purcell and Windermere periods, and finally so in the Jurasside or Nevadan revolution. The first deformation left a remnant trough of geosynclinal type (though probably not of any great size) on the eastern flank of the new uplands. It lasted through Windermere and early and medial Cambrian times. The deposits within it are seen now as the Windermere series of the Selkirk and neighbouring mountains, the Lower Cambrian grits and phyllites and the Middle Cambrian Canyon Creek slates of the Dogtooth Mountains. This trough was separated, by the Fairmont-Radium positive axis, from a second similar trough lying on the north and west flanks of old Montania. This was the "Colville Embayment" of Deiss (see p. 53). The deposits of these twin troughs are of geosynclinal type, and can lay some claim to being of geosynclinal thickness.

Both of them lay, however, to the *west* of the present position of the Rocky Mountain Trench. To the east of the Trench, neither the thickness nor the lithology of the Cambro-Ordovician succession implies geosynclinal conditions. The thick orthoquartzite-limestone facies of the Lower and Middle Cambrian is that of the stable shelf association—the deposits of an epeirogenic platform of the post- orogenic foreland rather than those of an unstable trough in a pre-orogenic down-buckle. They follow, in fact, the reasonably predictable foreland sequence in a compound marine transgression, as follows:—

(i) Near-shore facies of the shoal platform, deposited under turbulent, aerobic conditions: LOWER CAMBRIAN.

(ii) Shelf limestones of less turbulent environment when the supply of clastic material was greatly reduced; some small biostromal reefs on the forward edge of the shelf: EARLY MIDDLE CAMBRIAN.

(iii) True reef-off-reef pattern with intervening starved basins; clastic limestone and shale of foreland, siliceous shales and evaporites of starved basins: LATE MIDDLE CAMBRIAN.

(iv) Shallow-water shales, marls, and salt-pan of post-reef phase, followed by pure limestones of stable shelf on second cycle of transgression: EARLY UPPER CAMBRIAN.

(v) Normal final stage of foreland depositional cycle after regional subsidence—shales and limestones of subsiding clinoform, without intervening reef-phases: LATE UPPER CAMBRIAN AND EARLY ORDOVICIAN.

(vi) Early phases of earth movement, probably largely taphrogenic in this region and reflecting the more violent Taconian movements which were about to reach a climax in the eastern part of the continent; fragmentation of the western portion of the depositional basin into isolated smaller basins, some of silled type, with intervening areas of erosion; hence the bevelling of early Ordovician shales and limestones in areas separating basins of black graptolitic shale: LATE LOWER ORDOVICIAN.

Between this true foreland belt and that of the (already deformed) marginal geosyncline lay a transitional zone in which the deposits approached geosynclinal thickness but were not of geosynclinal character. This belt eventually developed into the western sector of the Main Ranges sub-province and the eastern part of the Western Ranges sub-province: it may, in early Palaeozoic times, have been fifty or more miles wide. The Lower Cambrian is wholly hidden in this zone; but throughout mid-Cambrian times calcareous material was swept from the turbulent eastern platform into the adjacent subsiding trough, where it was intimately intermingled with argillaceous material. This produced a fondoform facies, now represented chiefly by the Chancellor group. During its deposition, there were at least two periods of minor reef development on the eastern platform. Farther east still, in the zone now occupied by the Front Ranges sub-province, the clastic limestone facies mingled with fine detritus from the eroded Beltian of Montania. Here the depositional basin was partially protected by the reef developments on the platform, so that conditions in it were much less turbulent, and in part at least anaerobic. This allowed the preservation of the colours of the sediments derived from the Beltian, as well as the formation of a good deal of glauconite. This cycle (that of the Middle Cambrian) was ended by a compressional narrowing of the basin, elevating both the eastern and western margins and accelerating subsidence in the central zone. The second transgression, which resulted from this rejuvenation, began as before with the limestones of the sinking shoal platform. Marginally they were dolomitized; centrally they were thicker and more cherty, and remained calcareous (Ottertail formation). This cycle developed in the normal manner, without reefs, through a great series of mini-cycles of thinly-alternating shales and limestones (Goodsir group). This again was thickest and most cherty of the central portion of the trough.

This survey has so far taken us only into the early Ordovician. However, enough has perhaps already been said to indicate that the true Beltian geosyncline ceased to exist in pre-Windermere time; that the remnant left extended west of the Rocky Mountain Trench only for some early portion of Cambrian time (it may have been non-marine or brackish in nature, as indeed may the whole Beltian trough); and that the Rocky Mountain depositional area was not strictly geosynclinal. It was not, in fact, "heading for disruption" as a true geosyncline might be said to be; at least it was not heading for it in the Palaeozoic. Its life as a sediment-receiving area was immensely longer than that of a true geosyncline, and was punctuated by a series of inconclusive disturbances. When the end did come, the resulting structures were not of Alpine type, the rocks were little metamorphosed, and they have been eroded since the Eocene without the exposure of any large central intrusions.

We have also demonstrated the feasibility of regarding the Chancellor group as the off-reef or non-carbonate representative of the Middle Cambrian phase of the cycle, and the Arctomys as beginning in starved basins behind the Eldon reefs and ending as the shallow water, post-reef phase before the onset of the second transgression. We have now to consider the significance of the gaps in the succession above the Lower Ordovician; the strange stratigraphic contrasts between the Western Ranges and the Front Ranges; and the origin of the gypsum.

To attempt an answer to these questions, it is necessary to consider the possibility that some not-so-common sedimentary rocks owe their formation to the fact that some type of periodic earth movement has actually begun. Coal measures, black pyritic shales, and thick primary gypsum, are examples of sediments which we consider to originate under these tectonic conditions. They each result from the fragmentation of a large depositional basin, near the end of its cycle, into a series of smaller basins. These smaller basins must become more or less silled or enclosed; they must be protected from major incursion by ordinary sea-waters; and they must continue to subside as individual basins when the intervening areas have stopped subsiding, or are actually being elevated. In other words, the conditions for the *formation* of such sediments begin with the onset of the first tremors, which may be truly orogenic or at this stage merely taphrogenic. The conditions for their *preservation* as sediments require the continuation of

those movements after their deposition has ceased. A paper of this type is not the vehicle for a long essay in justification of this view. All we would do here is draw the reader's attention to the association in space and time between the Carboniferous coalfields of the world and the Hercynian-Appalachian orogeny; and between the Cretaceous coalfields of limnic type and the Jurasside and Laramide orogenies. The great type-localities of Ordovicio-Silurian graptolites are similarly related, spatially and temporally, to the Taconian and Caledonian orogenies. Lastly, the concentration of the great sulphate-sequences in the Siluro-Devonian, the Permian, and the middle Tertiary, allies them with the three major orogenic episodes occurring since the Lipalian revolution.

To return to our stratigraphic problems. The close of Goodsir (McKay) time saw the first development of graptolitic shales (the Glenogle formation) in one or two narrow belts within the depositional area. In post-Glenogle time, no single formation can have been deposited over even the greater part of the Rocky Mountain trough until the Fairholme formation occupied the eastern and southern parts of it in the late Devonian. Gaps mean non-deposition, or erosion, or both; in any event, earth movements of some sort had already begun. In early Niagaran time, there was a second graptolitic episode, in almost the same area as the first (though less widespread). Shortly following this came the Burnais gypsum beds, again in practically the same areas—completely confined to the Western Ranges sub-province and the eastern fringe of the Purcells. If, as we believe, the Stanford Range gypsum is primary (Henderson, 1954), the requirements of physical chemistry are that it can never have been buried more deeply than about 2000 feet (or probably considerably less than this). Furthermore, the preservation of rocks of Harrogate age (very slightly younger than the gypsum) in the cores of tight isoclinal synclines in the Stanford and Brisco Ranges is evidence that, *at the time of folding*, there were no younger rocks above them. There is no geological evidence that the two greatest post-Harrogate formations, the Palliser and the Rundle, were ever deposited in the Stanford and Brisco Ranges. There is valid physico-chemical evidence that they cannot have been.

It therefore seems reasonable to conclude that, from Glenogle to mid-Devonian times inclusively, the depositional basin was extremely restricted and partly fragmented. The Western Ranges sub-province received an almost complete succession; the Front Ranges sub-province was wholly non-depositional, and indeed erosional to the extent that the Upper Cambrian was removed over the greater part of it. The earth movements, heralded by the graptolite basins and later by the gypsum, culminated in immediate post-Harrogate time with the raising of the western basin (so terminating the cycle there) and the lowering of the eastern foreland (thus initiating the cycle there). The greatest lowering took place around the northern margin of Montania, giving the prototype of the present Fernie Basin, which was a subsiding unit from late Devonian to early Cretaceous times, inclusively. Bounding it on the east and north was a newly submerged platform of bevelled Cambrian rocks, on which the first deposits of the new cycle were the algal-stromatoporoidal "mats" of the lower Fairholme. Thus the present first and second ranges exhibit a stratigraphic succession which lacks the Upper Cambrian (over much of the belt), the Ordovician, the Silurian, and the Lower and Middle Devonian. Apart from the Precambrian, this exact succession is all that is present in many parts of the Western Ranges.

Dates of Deformation

We now see that there is some evidence that there was an important disturbance in the Rocky Mountains in immediate pre-Fairholme time. The stratigraphic relief on the bevelled Cambrian surface in the first range, overlain by Upper Devonian sediments, shows that this disturbance was post-Cambrian, pre-late Devonian in age.

Since the Rocky Mountain Trench has a trend, as a structural lineament, which appears to ally it more closely with the Laramide orogeny than with the Nevadan, and since also it forms

for a great distance the abrupt boundary between the disturbed belts of these two periods, there is strong implicit suggestion that the Nevadan (Jurasside) orogeny must have carried some effect into the Rocky Mountain area. This it doubtless did. A well known illustration is the ancestral Turner Valley fold, believed to have originated in pre-Fernie time (Gallup, 1951, pp. 817-821). The Nevadan disturbances left the Rocky Mountain depositional area with a discontinuous trough of geosynclinal proportions, in which the Kootenay and Blairmore coal-measures were accumulated. It was this trough which was deformed by the Laramide orogeny, raising the Front Ranges and the Foothills.

But, it will be objected, how could the Front Ranges and the Foothills be raised independently of the Main and Western Ranges? They could not; but, equally, the Rocky Mountains as a whole could not be raised independently of the Purcell, Cariboo, and Omineca Mountains. The exact mechanics of Rocky Mountain deformation are outside our understanding at present, but that they involve an eastward movement of the block lying west of the Trench is unavoidable. That block was certainly moving in Precambrian times; the 2000-foot Toby conglomerate rests with major angular unconformity on the Purcell series. It was also moving at various later periods, because there are several periods of metamorphism represented in the so-called Shuswap terrain, and several big gaps in the stratigraphic succession east of the Trench. The Laramide movements were merely the last of a series, as far as Western Canada is concerned. They were among the greatest, certainly, but there was mountain building and mountain destroying in the Cordilleran super-province more than once before the Laramide.

It is probable, in our view, that every major Rocky Mountain structure west of the Sulphur Mountain fault originated well before the close of Cretaceous time, some of them possibly before the end of the Palaeozoic. From Beaverhill Lake time onwards, the thickest and most continuous deposition in the entire geological province was in what is now the Fernie Basin. But there is no Triassic there. The likelihood is that it was never deposited so far to the west in the Rocky Mountain province. No beds of Permian age have ever been identified anywhere in the southern Rocky Mountains. Yet Permian and Triassic rocks are very widespread in the interior of British Columbia, as parts of the Milford and other large groups. Moreover, they are in large part volcanic and of geosynclinal type, and they have been involved in at least one period of severe orogeny and metamorphism ante-dating the Laramide.

It is thus a fair inference that a portion of the Rocky Mountain depositional area, including the prototype of the otherwise-subsiding Fernie Basin, was relatively *raised* during the Cordilleran equivalent of the Appalachian movements. We may also infer that another portion, mostly lying to the east of the raised portion but, like it, including the Fernie Basin, was relatively *depressed* in the Nevadan revolution. Yet it remains true that no single angular unconformity of any magnitude is known in the whole Rocky Mountain province south of Athabasca River. Epeirogenic movements presumably do not affect comparatively narrow depositional belts in generally subsiding areas; it is difficult, at least, to see how they could do so as a result of orogenic disturbance in an adjoining belt. We therefore conclude that the movements affecting the Rocky Mountain province during the Appalachian and Nevadan revolutions were dominantly taphrogenic; the structures originating from them were fault-structures.

The Western Ranges sub-province may have been the site of some faulting in the late Palaeozoic, as we have already indicated (p. 41 of this guidebook). The Chancellor fault and the Castle Mountain thrust must, however, be the oldest major structures in the southern Rocky Mountains; the structural wedge which they control is responsible for the westerly overturning in the Western Ranges, and this overturning is cut by the early-formed Stanford and Redwall faults. Moreover, if our interpretation is near the truth (Figure 1), the Chancellor and Castle Mountain faults *originated* before any of the faults farther east; much of the movement along the latter must have taken place as a result of further movement along the Castle Moun-

tain thrust. The movements along such great thrusts must have gone on over a very long period before culminating in the Laramide revolution. There is some circumstantial evidence that the Bourgeau and Lewis faults also originated early in the structural history of the mountain system. The folding of both faults, and the fact that they now virtually circumscribe the early formed Fernie Basin (which is not *crossed* by any Laramide structure of magnitude anywhere near that of the two faults concerned), are aspects of this evidence.

On this theory, then, the fault-panel of the Main Ranges sub-province is of pre-Laramide *origin*.. From small beginnings as a result of movements farther west, the panel underwent an unknown amount of relative elevation, with respect to the belts immediately flanking it, before the onset of the major Laramide orogeny. It then was able, during this disturbance, to move dominantly upwards as the whole system was translated horizontally, the crustal shortening being taken up almost entirely by the beds *below* the already existing thrust faults. The upward movement would constitute a bodily lifting of the mass of rock overlying the easterly-dipping underthrust (the Chancellor fault). Thus the Chancellor fault would have to undergo progressive flattening, for which there was no need in the case of the Castle Mountain thrust. Hence the dynamic metamorphism above (and presumably also below) the Chancellor fault, which has no parallel in the case of the Castle Mountain thrust.

The Sheared Zone Between the Brisco-Stanford and Ottertail-Mitchell Ranges

The White River Break is a westerly-dipping fault which over a considerable part of its length is known to have Goodsir strata on both sides of it. The beds on the west side are overturned towards the west; those on the east side are in places overturned towards the east. The fault is younger than the westward overturning; its magnitude, and its influence on the Rocky Mountain Trench between Blaeberry and Bush Lakes, suggest that it can scarcely be post-Laramide in age. The westward overturning on the west side of the Break is attributed to the underthrusting below the easterly-dipping Chancellor fault. The eastward overturning east of the Break is presumably due to the late Laramide thrust-episode in which the deformation culminated (pp. 31, 32). The White River Break is itself part of this episode, and may itself be responsible for the eastward overturning.

The tracts of Goodsir strata on the two sides of the break must therefore originally have been widely separated, as is substantiated by the facies differences on the two sides. The more westerly part was brought *below* the most easterly part by the underthrusting of the Chancellor fault, and in this process was overturned towards the *west*. This part was then raised again, into juxtaposition with the part above, by the later thrusting along the White River Break (Figure 1). The part above was in this last process overturned towards the *east*. That this approximately represents the course of events is attested by the fact that, where the Main Ranges sub-province has wedged out southward, there is no westerly overturning in the hanging wall of the White River Break. Overturning in the Hughes Range is towards the east.

Deformation of the Front Ranges

The several major thrust faults underlying the various front ranges are commonly shown in cross-sections as being spatially independent of one another, and all of about the same magnitude. They must, in this case, each bring about the same width and thickness of the same facies of the same formations to about the same elevation. This is not mechanically impossible, but it seems a remarkable coincidence. It seems, on fundamental grounds, much more likely that there is below the Front Ranges a single thrust fault, more or less flat, which originated as a near-bedding plane fault. It would therefore be overlain by a single slab of the same formations. Minor thrusting within this slab could then easily repeat the same sequence of beds

at approximately regular intervals. If this were so, the master thrust would be slightly older than the remainder, would lie below them, and would crop out farthest to the east. The McConnell fault should therefore be regarded as this master thrust, of a magnitude comparable with that of the Castle Mountain thrust and far greater than the Mount Rundle or Sulphur Mountain faults. The horizontal movement on either of the latter faults can be regarded as proportional to the horizontal distance between the trace of that fault and that of the next fault to the west. The horizontal movement on the McConnell fault would be similarly proportional to the horizontal distance between its trace and that of the Castle Mountain thrust. The Front Ranges sub-province is, in other words, structurally like the foothills, in which the great majority of mappable thrusts merely repeat about the same part of the stratigraphic section, above much greater sole faults which have nearly all their displacement at depth. As observed by Evans (1933, p. 164) and others, the McConnell fault is the most westerly fault in the Bow River section now mappable at the surface as a *flat thrust.* This suggests the possibility that the more westerly thrusts of comparable type and magnitude—the Castle Mountain thrust and the Dogtooth-Purcell thrusts— are older than the McConnell fault and the sole faults of the foothills, and have lost their forward-riding flat portions during a longer period of erosion.

Crustal Shortening

The amount of crustal shortening, across the present strike of the beds, has been very considerable. Walcott (1928, pp. 201-3) estimated it at 25 per cent, or 24 miles, which is a pure guess unsupported by any structural evidence. The actual shortening was in our view far greater than this, even across the Rockies in the strict sense. By drawing a series of cross-sections in which the structures of the unseen beds are interpreted as fairly as possible, we have arrived at an average figure for the shortening across the strike. Between the Purcell Trench and the McConnell fault (that is, excluding the Foothills but including the Dogtooth Mountains), the original basin appears to have been reduced to a half of its original width, or less. By a similar process, we estimate that the Rocky Mountain system at about the latitude of Banff, including the Rocky Mountain Trench and the Foothills, has suffered crustal shortening of approximately 100 miles. This is equivalent to a reduction in width of slightly more than 50 per cent. These figures we regard as conservative.

BIBLIOGRAPHY

General

Allan, J. A. (1914): Rocky Mountain Section between Banff and Golden; Geol. Surv., Canada, Summ. Rpt. 1912, pp. 165-176.

(1914): Geology of Field Map-Area, B.C. and Alberta; idem, Mem. 55.

Beach, H. H. (1943): Moose Mountain and Morley Map-Areas, Alberta; idem. Mem. 236.

Burling, L. D. (1914): Early Cambrian Stratigraphy in the North American Cordillera, with Discussion of the Albertella and Related Faunas; idem, Mus. Bull. 2, Geol. ser. 17.

(1923): Cambro-Ordovician Section Near Mount Robson, British Columbia; G.S.A. Bull., vol. 34, No. 4, pp. 721-748.

Campbell, C. D. (1947): Cambrian Rocks of Northeastern Stevens County, Washington; idem. vol. 58, No. 7, pp. 597-612.

Clark, L. M. (1949): Geology of Rocky Mountain Front Ranges near Bow River, Alberta; Amer. Assoc. Petrol. Geol., Bull., vol. 33, No. 4, pp. 614-633.

Daly, R. A. (1912): North American Cordillera, Forty-ninth Parallel; Geol. Surv., Canada, Mem. 38.

(1915): A Geological Reconnaissance between Golden and Kamloops, B.C.; idem. Mem. 68.

Deiss, C. F. (1938): Cambrian Formations and Sections in Part of Cordilleran Trough; G.S.A. Bull., Vol. 49, pp. 1067-1168.

(1939): Cambrian Formations of Southwestern Alberta and Southeastern British Columbia; idem, Vol. 50, pp. 951-1026.

(1940): Lower and Middle Cambrian Stratigraphy of Southwestern Alberta and Southeastern British Columbia; idem, Vol. 51, pp. 731-794.

(1941): Cambrian Geography and Sedimentation in the Central Cordilleran Region; Idem, Vol. 52, pp. 1085-1116.

Evans, C. S. (1933): Brisco-Dogtooth Map-Area, British Columbia; Geol. Surv., Canada, Summ. Rpt., 1932, A. II, pp. 106-187.

Gallup, W. B. (1951): Geology of Turner Valley Oil and Gas Field, Alberta; Amer. Assoc. Petrol. Geol., Bull., vol. 35, No. 4, pp. 797-821.

Hall, J. (1859): Geological Survey of New York; Palaeontology. Vol. III, Introduction.

Henderson, G. G. L. (1954): Geology of the Stanford Range; B.C. Dept. Mines, Bull. 35.

Howell, B. F. et al (1944): Correlation of the Cambrian Formations of North America; G.S.A. Bull., Vol. 55, pp. 993-1003.

Hughes, R. D. (1953): Geology of Portions of Sunwapta, and Southesk Map-Areas, Jasper National Park, Alberta; unpublished Ph.D. thesis, University of Oklahoma.

Lang, A. H. (1938): Preliminary Report, Keithley Creek Map-Area, Cariboo District, British Columbia; Geol. Surv., Canada, Preliminary Paper 38-16.

Lay, D. (1940-41): Fraser River Tertiary Drainage-History; B.C. Dept. Mines, Bull. 3 and 11.

Link, T. A. (1928): Relationship between Over- and Under-Thrusting as Revealed by Experiments; Amer. Assoc. Petrol. Geol., Bull., Vol. 12, No. 8, pp. 825-854.

Lord, C. S., Hage, C. O., and Stewart, J. S. (1947): The Cordilleran Region; Geol. Surv., Canada, Econ. Ser. 1, pp. 220-310.

McConnell, R. G. (1887): On the Geological Structure of a Portion of the Rocky Mountains; idem, Ann. Rpt. 1886, n.s., Vol. 2, D.

North, F. K. (1953): Cambrian and Ordovician of Southwestern Alberta; A.S.P.G. Guide Book, pp. 108-116.

Okulitch, V. J. (1949): Geology of Part of the Selkirk Mountains, British Columbia; Geol. Surv., Canada, Bull. 14.

and Roots, E. F. (1947): Lower Cambrian Fossils from the Aiken Lake Area, British Columbia; Trans. Roy. Soc. Canada, Ser. 3, Sec. IV, Vol. 41, pp. 37-46.

Park, C. F. and Cannon, R. S. (1943): Geology and Ore Deposits of the Metaline Quadrangle, Washington; U.S.G.S. Prof. Paper 202.

Rasetti, F. (1951): Middle Cambrian Stratigraphy and Faunas of the Canadian Rocky Mountains; Smithsonian Misc. Coll. Vol. 116, No. 5.

Rice, H. M. A. (1937): Cranbrook Map-Area, British Columbia; Geol. Surv., Canada, Mem. 207.

Schofield, S. J. (1915): Geology of the Cranbrook Map-Area, British Columbia; idem, Mem. 76.

1921): The Origin of the Rocky Mountain Trench, British Columbia; Trans. Roy. Soc. Canada, Ser. 3, Sec. IV, Vol. 14, pp. 61-97.

Walcott, C. D. (1928): Pre-Devonian Paleozoic Formations of the Cordilleran Provinces of Canada; Smithsonian Misc. Coll. Vol. 75, No. 5.

Walker, J. F. (1926): Geology and Mineral Deposits of Windermere Map-Area, British Columbia; Geol. Surv., Canada, Mem. 148.

and Bancroft, M. F. (1929): Lardeau Map-Area, British Columbia; idem. Mem. 161.

Warren, P. S. (1927): Banff Area, Alberta; idem. Mem. 153.

Wilson, A. E. (1926): An Upper Ordovician Fauna from the Rocky Mountains, British Columbia; idem. Bull. 44, pp. 1-34.

Front Ranges

Allan, J. A. (1914): Rocky Mountain Section between Banff and Golden Along the Canadian Pacific Railway; Geol, Surv., Canada, Summ. Rpt. 1912, p. 165-176.

and Carr, J. L. (1947): Geology of the Highwood-Elbow Area, Alberta; Res. Council, Alta., Rpt. 49.

———, Warren, P. S., and Rutherford, R. L. (1932): A Preliminary Study of the Eastern Ranges of the Rocky Mountains in Jasper Park, Alberta; Trans. Roy. Soc. Canada, Ser. 2, Sec. IV, Vol. 26, pp. 226-249.

Beach, H. H. (1943): Moose Mountain and Morley Map-Areas, Alberta; Geol. Surv., Canada, Mem. 236.

Beales, F. W. (1950): Late Palaeozoic Formations of Southwestern Alberta; Geol. Surv., Canada, Paper 50-27.

——— (1953): Dolomitic Mottling in Palliser (Devonian) Limestone, Banff and Jasper National Parks, Alberta; Amer. Assoc. Petrol. Geol., Bull., Vol. 37, p. 2281.

Clark, L. M. (1949): Geology of Rocky Mountain Front Ranges near Bow River, Alberta; Amer. Assoc. Petrol. Geol., Bull., Vol. 33, No. 4, pp. 614-633.

Crockford, M. B. B. (1949): Geology of Ribbon Creek Area, Alberta; Res. Council Alta. Rpt. 52.

DeWit, R., and McLaren D. J. (1950): Devonian Sections in the Rocky Mountains between Crowsnest and Jasper, Alberta; Geol. Surv., Canada, Paper 50-23.

Douglas, R. J. W. (1953): Carboniferous Stratigraphy in the Southern Foothills of Alberta; A.S.P.G. Guide Book, pp. 68-88.

Douglas, R. J. W. (1950): Callum Creek, Langford Creek, and Gap Map-Areas, Alberta; Geol. Surv., Canada, Mem. 255.

Dowling, D. B. (1905): The Cascade and Costigan Coal Basins and their Continuation Northward; Geol. Surv., Canada, Summ. Rpt. 1904.

Fox, F. G. (1951): Devonian Stratigraphy of Rocky Mountains and Foothills between Crowsnest Pass and Athabaska River, Alberta, Canada; Amer. Assoc. Petrol. Geol., Bull., Vol. 35, No. 4, pp. 822-843.

Goodman, A. J. (1951): Tectonics of East Side of Cordillera in Western Canada; Amer. Assoc. Petrol. Geol., Bull., Vol. 35, No. 5, pp. 783-796.

Harker, P. (1951): Stratigraphy and Paleontology of the Banff and Associated Carboniferous Formations of Western Canada; Univ. of Michigan Thesis, available in Geological Survey Library, Ottawa.

Kelly, W. A. (1936): Middle and Upper Paleozoic Formations in the Canadian Rockies (Abstract); G.S.A. Proc., pp. 380-381.

——— (1939): Devonian and Mississippian Stratigraphy of Jasper Park, Alberta (Abstract); G.S.A. Bull., Vol. 50. p. 2000.

Kindle, E. M. (1929): The Succession of Fossil Faunas in the Eastern Part of Jasper Park; Am. Jour. Sc. 5th Ser. Vol. 18, pp. 177-192.

Laudon, L. R. (1949): Devonian and Mississippian Stratigraphy, Wapiti Lake Area, British Columbia; Amer. Assoc. Petrol. Geol., Bull., Vol. 33, p. 1502-1522.

McConnell, R. G. (1887): Report on the Geological Structure of a Portion of the Rocky Mountains, Accompanied by a Section Measured near the 51st Parallel; Geol. Surv., Canada, Ann. Rpt. 1886.

MacKay, B. R. (1931): Corbin Coal Field, British Columbia; Geol. Surv., Canada, Summ. Rpt., 1930, A, pp. 154-179.

——— (1932): The Mesozoic-Palaeozoic Contact and Associated Sediments, Crowsnest District, Alberta and British Columbia; Geol. Surv., Canada, Summ. Rpt., 1931, B pp. 1-25.

——— (1934): Michel Coal Area, British Columbia; Geol. Surv., Canada, Summ. Rpt., 1933, B, p. 1-19.

McLaren, D. J. (1953): Summary of the Devonian Stratigraphy of the Alberta Rocky Mountains; A.S.P.G. Guide Book, pp. 89-104.

Newmarch, C. B. (1953): Geology of the Crowsnest Coal Basin with Special Reference to the Fernie Area; B.C. Dept. Mines, Bull. 33.

North, F. K. (1953): Cambrian and Ordovician of Southwestern Alberta; A.S.P.G. Guide Book, pp. 108-116.

Raymond, P. E. (1930): The Paleozoic Formations in Jasper Park, Alberta; Am. Jour. Sc., 5th Ser. Vol. XX, p. 289-300.

Shimer, H. W. (1913): Spirifers of the Lake Minnewanka Section, Alberta; G.S.A. Bull., Vol. 24, p. 233-240.

——— (1926): Upper Paleozoic Fauna of the Lake Minnewanka Section, Near Banff, Alberta; Geol. Surv., Canada, Bull. 42, p. 1-89.

Warren, P. S. (1927): Banff Area, Alberta; Geol. Surv., Canada, Mem 153.

(1928): The Palaeozoics of Crowsnest Pass, Alberta; Trans. Roy. Soc. Can., Series 2, Sec. IV, Vol. 22, p. 109-119.

(1937): Age of the Exshaw Shale in the Canadian Rockies; Am. Jour. Sc., 5th Ser., Vol. 33, p. 454-457.

(1947): Age and Subdivisions of the Rocky Mountain Formation at Banff, Alberta; G.S.A. Bull., Vol. 58, p. 1238.

Precambrian

Allan, J. A. (1913): Rocky Mountains; Bankhead to Golden; XII Int. Geol. Congress, Guide Book No. 8, pp. 172-4, 192, 194-5.

(1914): Geology of Field Map-Area; Geol. Surv., Canada, Mem. 55, pp. 61-2.

Burling, L. D. (1914): Early Cambrian Stratigraphy in the North American Cordillera; Geol. Surv., Canada, Mus. Bull. 2, Geol. Series 17, pp. 2-19.

Daly, R. A. (1912): North American Cordillera, 49th parallel; Geol. Surv., Canada, Mem. 38, especially Part 1, pp. 47-280.

(1913): Introduction to the Geology of the Cordillera; XII Int, Geol. Congress, Guide Book No. 8, pp. 132-142.

(1915): Golden to Kamloops, British Columbia; Geol. Surv., Canada, Mem. 68, especially pp. 58-115.

Douglas, R. J. W. (1952): Waterton, Alberta; Geol. Surv., Canada, Preliminary Paper 52-10; map only.

Dyson, J. L. (1950): The Geologic story of Glacier National Park; Glacier Natural History Association, Special Bulletin No. 3, pp. 1-24.

Evans, C. S. (1933): Brisco-Dogtooth Map-Area, British Columbia; Geol. Surv., Canada, Summ. Rpt. 1932, pt. A, pp. 116-119.

Fox, F. G. (1953): Glossary of Formation names of Southwestern Alberta; A.S.P.G. Guide Book, pp. 180-185.

Hage, C. O. (1941): Preliminary Map, Beaver Mines, Alberta; Geol. Surv., Canada, Preliminary Paper 41-42.

Hume, G. S. (1933): Waterton Lakes-Flathead Area, Alberta and British Columbia; Geol. Surv., Canada, Summ. Rpt., 1932, B, pp. 1-20.

Okulitch, V. J. (1949): Geology of part of the Selkirk Mountains in the Vicinity of the Main Line of the C.P.R.; Geol. Surv., Canada, Bull. 14, pp. 1-21.

Rice, H. M. A. (1937): Cranbrook Map-Area, British Columbia; Geol. Surv., Canada, Mem. 207, pp. 4-18.

Schofield, S. J. (1913): Elko to Kootenay Lake, XII Int. Geol. Congress, Guidebook No. 9, pp. 46-51.

(1914): The Pre-Cambrian (Beltian) Rocks of Southeastern British Columbia and their Correlation; Geol. Surv., Canada, Mus. Bull. 2, Geol. Series 16, pp. 1-13.

(1915): Cranbrook Map-Area; Geol. Surv., Canada, Mem. 76, especially pp. 23-52, 56-85, 92-103.

(1922): Relationship of the Pre-Cambrian (Beltian) Terrain to the Lower Cambrian Strata of Southeastern British Columbia; Geol. Surv., Canada, Mus. Bull. 35, Geol. Series 42, pp. 3-15.

Swanson, C. O. and Gunning, H. C. (1945): The Geology of the Sullivan Mine; Trans. C.I.M.M., Vol. 48, pp. 645-667.

Walcott, C. D. (1910): Pre-Cambrian Rocks of the Bow River Valley, Alberta; Smithsonian Misc. Coll., Vol. 53, No. 7.

(1910): Abrupt Appearance of Cambrian Fauna on the North American Continent; idem, vol. 57, No. 1.

(1914): Pre-Cambrian Algonkian Algal Flora; idem, Vol. 64, No. 2.

(1928): Pre-Devonian Palaeozoic Formations of the Cordilleran Provinces of Canada; idem, Vol. 75, No. 5, pp. 256-8, 299-300.

Walker, J. F. (1926): Geology and Mineral Deposits of Windermere Map-area, British Columbia; Geol. Surv., Canada, Mem. 148, pp. 6-21.

THE ROCKY MOUNTAIN TRENCH

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INTRODUCTION

The Rocky Mountain Trench is the most prominent single lineament in the Rocky Mountain system. This remarkable feature has been the subject of a great deal of debate in the literature, and any new contribution should begin with a review of previously expressed opinion. We are grateful to Dr. E. F. Roots for his permission to make use of an excellent summary, which he prepared for the graduate school at Princeton University. Much of the following descriptive data, the entire series of summaries of previously published opinions, and the greater part of the bibliography, are taken with only minor alterations from Dr. Roots' paper. Our own views on the nature and origin of the Trench are given separately at the end. The terminology employed for geologic provinces and sub-provinces, and for major faults, is that defined in the previous paper in this guidebook, and illustrated on the tectonic map which accompanies it.

DEFINITION AND DESCRIPTIVE DATA

The term "trench" in a geologic sense was defined by Daly (1912, p. 26) as a "long, narrow, intermontane depression occupied by two or more streams alternately draining the depression in opposite directions." The type example is the depression lying west of the Rocky Mountains in Montana and British Columbia, and possibly in the Yukon, a depression which Daly named the Rocky Mountain Trench.

This trench extends in a nearly continuous and remarkably straight line from Flathead Lake, Montana (latitude 48°N) to old Chee House on Kechika River, in northern British Columbia (latitude 59°30'N). Calkins (1909, p. 11) and others would continue it farther to the south, into the valley of the Bitterroot River. Others, including the compilers of the Tectonic Map of Canada, make it reappear north of the Liard Plain and continue to the Alaska boundary, and presumably still farther.

Its total length is therefore almost 1,000 miles, and with the possible extensions it may be more than 1,500 miles. Both these figures include a part approximately 100 miles long, near latitude 55°N, where the Trench has no distinct topographic expression, though the underlying structure may continue unbroken. The larger figure also includes a further part, from the Liard Plain northward, where there is no longer a trench in Daly's sense. The Trench is from 2 to 10 miles wide (locally 17 miles at Kimberley), and its floor is everywhere, except in the 100-mile "break," 4,000 to 9,000 feet below the mountain summits on each side. The average strike of the Trench is N. 33°W., though parts of the southern portion trend almost due north-south.

The Trench is a nearly flat bottomed, parallel sided trough, drained by at least nine rivers, and possibly ten. From south to north, these are: Flathead (S[2]), Kootenay (S), Columbia (N[2]),Canoe (S), Fraser (N), Parsnip (N), Finlay (S), Fox (S), and Kechika (N); and possibly the Liard (S). The width and depth of the Trench bear no necessary relation to the size of the stream now occupying the valley. Most of the streams and their tributaries enter or leave the Trench through canyons.

The Trench appears to form the physiographic and structural boundary between the Rocky Mountains on the east, and the en echelon ranges of the Interior Cordilleran systems on the west. From about Golden northward, however, it is apparently a Rocky Mountain feature, and it is parallel to the *general* Rocky Mountain trend (to the Front Ranges, for instance, or to the

[1] Geologists, The California Standard Company, Calgary, Alberta.
[2] N—north-flowing; S—south-flowing

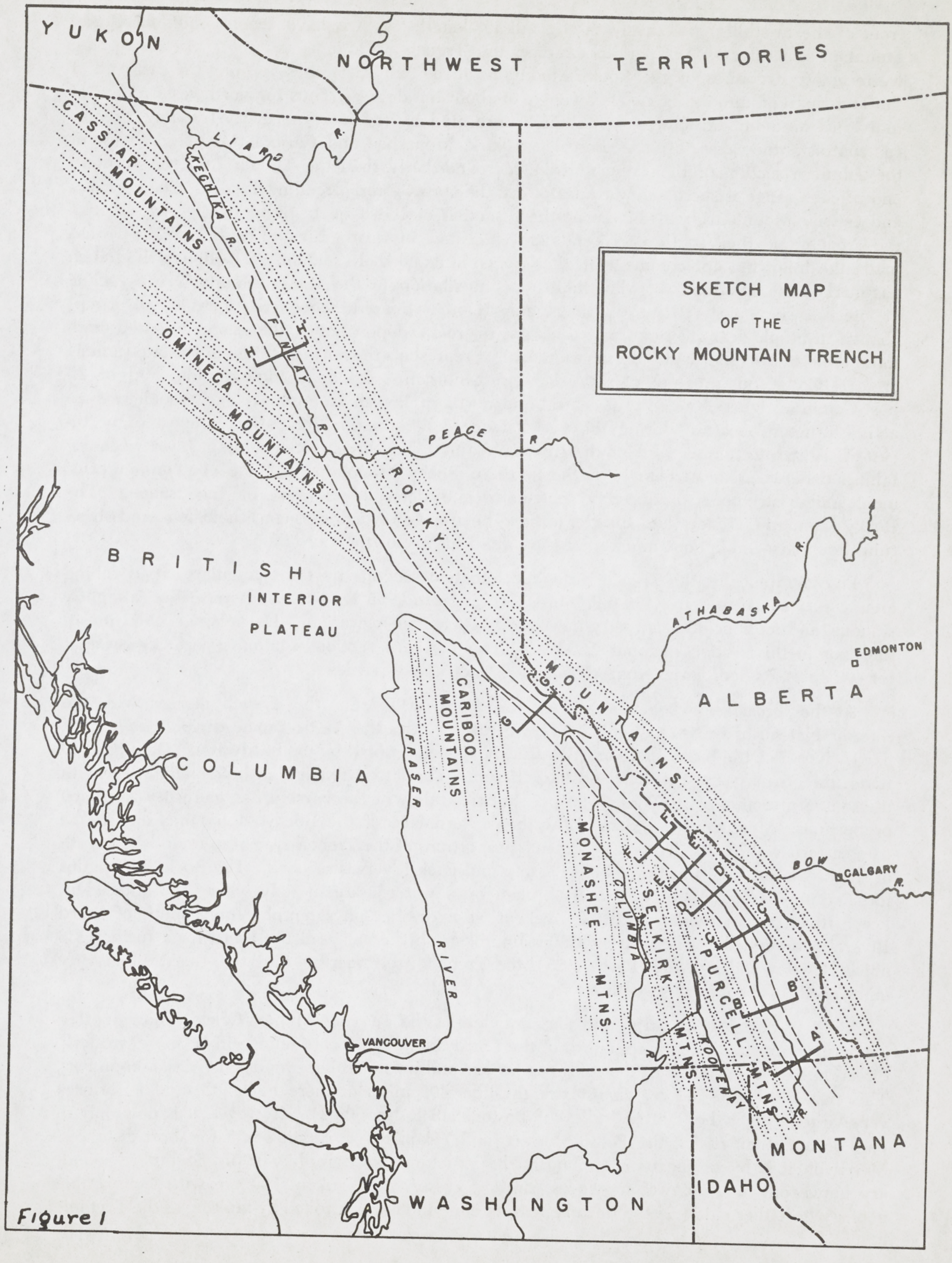

SKETCH MAP
OF THE
ROCKY MOUNTAIN TRENCH
YUKON
NORTHWEST TERRITORIES
CASSIAR MOUNTAINS
LIARD R.
KECHIKA R.
FINLAY R.
OMINECA MOUNTAINS
PEACE R.
ROCKY MOUNTAINS
BRITISH COLUMBIA
INTERIOR PLATEAU
CARIBOO MOUNTAINS
FRASER RIVER
ATHABASKA R.
EDMONTON
ALBERTA
MONASHEE MTNS.
COLUMBIA R.
SELKIRK MTNS.
PURCELL MTNS.
KOOTENAY R.
BOW R.
CALGARY
VANCOUVER
MONTANA
IDAHO
WASHINGTON
A
B
C
D
E
F
G
H

Figure 1

front of the Foothills) practically throughout its length (as we have seen, *individual* Rocky Mountain structures are not parallel either to the Trench or to one another). In detail, the westernmost structures of the Rocky Mountains at the two extremities, forming the east wall of the Trench, trend into the Trench at an angle of about ten degrees. Thus the northwestern ends of individual Mountain structures are obliquely truncated by the more northerly trending Trench. In contrast, the axes of the Purcell, Selkirk, Monashee and Caribou Mountains, west of the southern section of the Trench, strike more northerly than the Trench, and the northern end of each range is successively truncated by the northwesterly trending Trench. The Omineca and Cassiar Mountains, west of the northern section of the Trench, trend more westerly than the Trench, and their southeastern ends are truncated in turn. Roots (1954, pp. 194-6) has made the following apt comment on the Trench in its northern section. "The line of the trench has marked the apparent westward limit of sedimentation in the Rocky Mountain geosyncline at intervals since early Palaeozoic times, and at other times has been the locus of an abrupt change in lithological character and thickness of rocks deposited to the east compared with those deposited to the west. So far as known, it represents the northeast limit of the late Jurassic or early Cretaceous orogeny, of all earlier (post-Silurian) periods of deformation, and of all post-Cambrian igneous activity in central and northern British Columbia. The trench was an active structural feature during the post-Paleocene deformation that affected most of northeastern British Columbia west of the Interior Plains. No direct connection has yet been established between the structures of the northern Rocky Mountains and the contemporaneous, much milder structures produced by post-Paleocene deformation west of the trench. The Rocky Mountain Trench thus appears to have been a major depositional, lithological, and structural boundary throughout much of the recorded history of the Cordillera."

Physiographically, the Trench is divided into two sections by the triangular-shaped rolling area which constitutes the 100-mile "break" near latitude 55°N. The southern section is slightly sinuous, and its floor does not vary more than 700 feet in elevation. The average elevation of the floor in this section is about 2,300 feet. The northern section is almost perfectly straight for 400 miles; its floor varies from 1,900 to 3,200 feet above sea level.

At the "break" between the two sections, the west side of the Trench merges with the Interior Plateau of British Columbia. This break includes the Arctic-Pacific divide (Lay, 1941, p. 8). North of the break there are two trenches, one occupied by the headwaters of the Parsnip River, the other by the Crooked and Pack Rivers. The latter trench is in better alignment with the southern section of the Trench proper, but the valley of the Parsnip has more nearly trench proportions. Moreover, its eastern wall is the western face of the Rocky Mountains and so the true eastern wall of the Trench. The full proportions of the Trench are not re-established north of the break until the junction of the Parsnip and Pack Rivers is reached. The Rocky Mountains form an almost continuous east wall (broken by a water gradient only where the antecedent Peace River crosses them), until they die out, as a distinct physiographic unit, south of Liard River. Although the west wall continues unbroken up the valley of the Liard for a further 150 miles (Hedley and Holland, 1941, p. 25), the Trench itself merges into the Liard Plain fifty miles north of Terminus Mountain.

Both Bostock (1948, map) and the compilers of the Tectonic Map of Canada show another major structural zone beginning north of the Liard Plain, and continuing, in a more westerly direction than the Trench to the south, as far as (and presumably beyond) the Alaska boundary. This part also describes an almost straight line, 400 miles or more in length, and it forms a very large valley (the Tintina Valley of Bostock, 1948, pp. 60-62). However, it is now only in part occupied by rivers, the Pelly, Stewart, and Yukon Rivers running in it for short distances. Moreover, it is by no means continuously the structural, stratigraphic, or physiographic boundary between two geological provinces, since it crosses the Yukon Plateau with comparable geology on either side. If the lineament is as continuously controlled by faulting as the Tectonic

Map suggests, however, it surely must bear some relationship to the Trench in spite of the diagonal intervention of the Pelly Range. The Trench in this wide sense is readily divisible into *three* sectors. The dividing areas are that near latitude 55°N, where the Trench in part merges with the Interior Plateau, and that of the Liard Plain astride latitude 60°N.

In contrast to the Rocky Mountains forming the east wall, the successive mountain ranges forming the west wall show great complexity of rock type and structure, and all are characterized by a significant proportion of intrusive and metamorphic rocks. Furthermore, there is general agreement that the main structures west of the Trench are older than those of the Rocky Mountains, having developed during the Nevadan (Jurasside) revolution or still earlier (Warren, 1938, p. 66; Evans, 1933, p. 164). Northward from Golden, none of the structures on the west side of the Trench have been shown to extend to the east side. Southward from Golden, no structure has been *proven* to cross the Trench, but there is some evidence that a number of faults may do so (e.g., the Moyie and Cranbrook faults). Southward from Wasa, which is 18 miles north of Cranbrook, the contrast between the mountain systems on the two sides largely disappears, and the Trench loses much of its regularity of form. As far as Kalispell, Montana, however, it continues essentially unbroken.

STRUCTURE OF THE TRENCH AS DEMONSTRATED BY PREVIOUS WORKERS[1]

INTERNATIONAL BOUNDARY, LATITUDE 49°: SECTION A

The Trench is here found on the eastern part of a tilted fault block, which has a large downthrow on its east side. Devonian strata are exposed along the eastern edge of the fault block, resting on late Precambrian rocks. Both the bordering ranges are composed of late Precambrian formations. The fault on the east side was interpreted by Daly as a normal fault, but Shepard (1922 A, p. 130) has given evidence that it is reversed. Clapp (1932, pp. 19, 24) traced this type of faulting southward to Flathead Lake.

CRANBROOK, LATITUDE 49°30′: SECTION B.

Devono-Carboniferous strata form the floor of the Trench, and are in contact with Precambrian rocks along a major fault at its east side. The main fault zone which separates the structures of the Rocky Mountains from those of the Purcell Range lies in the Rockies about 12 miles east of the Trench, and does not here form a topographic valley. The Precambrian rocks east of the Trench, however, trend essentially parallel to the main Rocky Mountain structure, in general more northwesterly than the northerly strike of the rocks on the west side. The rocks of the two flanks belong to different members of the Proterozoic Purcell series.

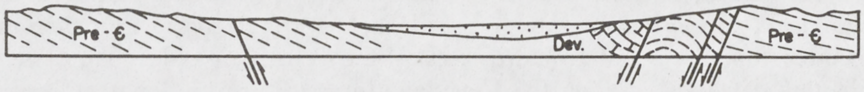
WINDERMERE, LATITUDE 50°: SECTION C

The Proterozoic strata west of the Trench are overturned towards the east, and plunge to the northwest (Walker, 1926, p. 40). The Palaeozoic strata east of the Trench are highly folded and faulted, and are in many places overturned towards the west. The Trench floor is an intensely folded and faulted zone, which separates the structures of the Rocky Mountains from those of the mountains to the west. According to Walker, however, there are no true border faults along the Trench within the Windermere map-area (1926, p. 40).

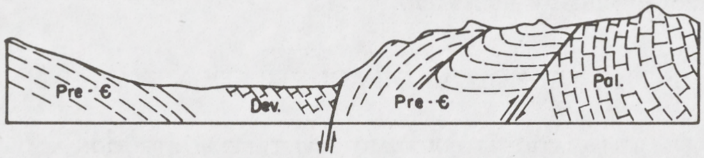
SPILLIMACHEEN, LATITUDE 51°: SECTION D

In this area elongated rock ridges of folded and faulted Palaeozoic rocks rise from the Trench floor. The Precambrian rocks to the west are overturned towards the east, and have

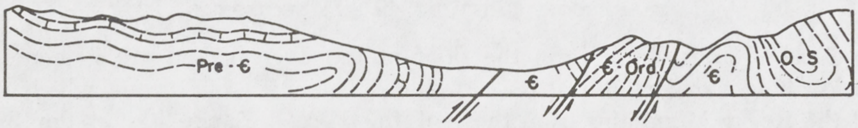
[1] See Figures 2 and 3.



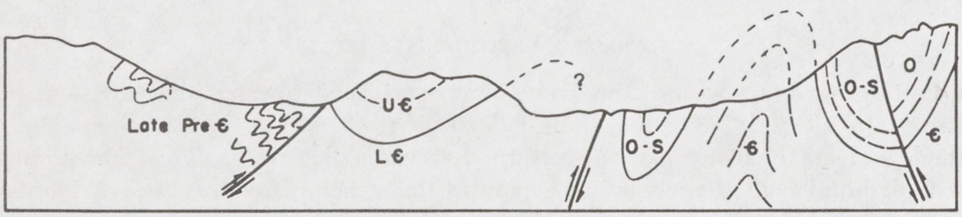
SECTION A-A' AT 49°N - INTERNATIONAL BOUNDARY
(DALY)



SECTION B-B' AT 49°30'N - CRANBROOK
(SCHOFIELD AND SHEPARD)

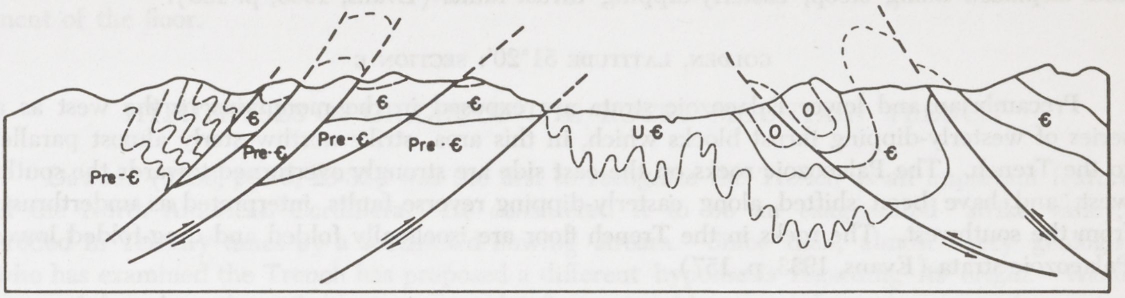


SECTION C-C' AT 50°N - WINDERMERE
(WALKER)

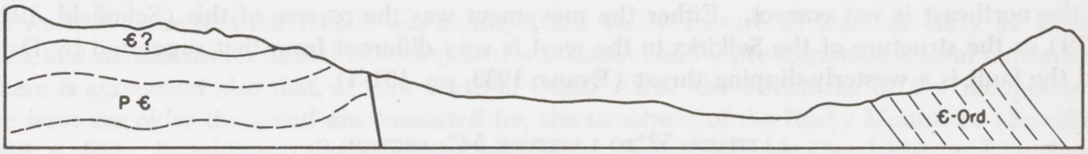


SECTION D-D' AT 51°N - THROUGH INTRAVALLEY RIDGE - SPILLIMACHEEN
(EVANS)

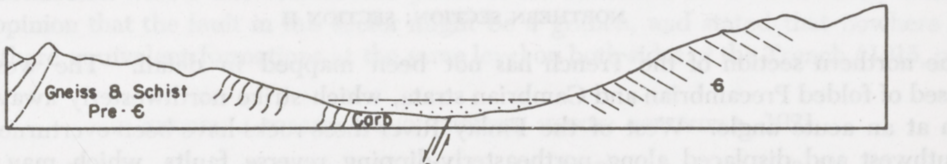
Figure 2



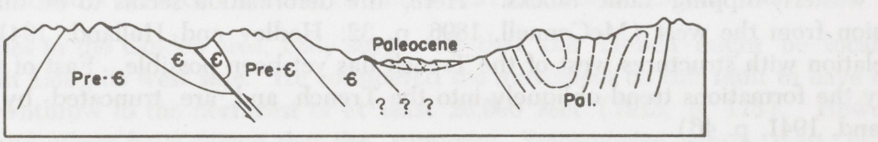
SECTION E-E′ AT 51°·20′N - GOLDEN
(EVANS)



SECTION F-F′ AT 51°·40′N - DONALD
(DALY)



SECTION G-G′ AT 53°N
(McEVOY AND MALLOCH)



SECTION H-H′ AT 57°N - FINLAY RIVER
(HEDLEY AND HOLLAND, ROOTS)

Figure 3

been thrust eastward. The Palaeozoic rocks to the east have been overturned towards the west, and displaced along steep, easterly-dipping thrust faults (Evans, 1933, p. 155).

GOLDEN, LATITUDE 51°20′: SECTION E

Precambrian and lower Palaeozoic strata are exposed in the mountains to the west as a series of westerly-dipping thrust blocks which, in this area, strike northwesterly almost parallel to the Trench. The Palaeozoic rocks on the east side are strongly overturned towards the southwest, and have been shifted along easterly-dipping reverse faults, interpreted as underthrusts from the southwest. The rocks in the Trench floor are isoclinally folded and drag-folded lower Palaeozoic strata (Evans, 1933, p. 157).

DONALD, LATITUDE 51°45′: SECTION F

Daly (1915, p. 113) mapped a major fault along the west side of the Trench, between highly metamorphosed sediments, which he considered late Precambrian, on the west, and Cambro-Ordovician rocks of the valley floor and the mountains to the east. Later work by Drysdale (1917, p. 61) and by Schofield (1923, p. 85) showed the rocks to the west to be partly late Palaeozoic in age; thus Daly's interpretation of the fault as a normal fault with downthrow on the northeast is not correct. Either the movement was the reverse of this (Schofield, 1921, p. 79) or the structure of the Selkirks to the west is very different from that suggested by Daly, and the fault is a westerly-dipping thrust (Evans, 1933, pp. 151-5).

LATITUDE 52°TO LATITUDE 54°: SECTION G

Few detailed observations have been made in this section, but, in general, mapping has shown the Trench to follow the contact between Precambrian rocks to the west and lower Palaeozoic rocks in the Trench floor and to the east. The rocks on both sides and in the floor are much faulted and crushed. Most writers have postulated a steep longitudinal fault of essentially vertical displacement (Coleman, 1890, p. 100; McEvoy, 1900, p. 38; Malloch, 1910, p. 126; Schofield, 1921, p. 81; Lay, 1941, p. 20).

NORTHERN SECTION: SECTION H

The northern section of the Trench has not been mapped in detail. The west wall is composed of folded Precambrian and Cambrian strata, which strike northwesterly away from the Trench at an acute angle. West of the Finlay River these rocks have been overturned towards the southwest and displaced along northeasterly-dipping reverse faults, which may represent underthrusts from west. West of the Kechika River the rocks have undergone very complex folding, and in the main appear to be overturned and overthrust from the west (Hedley and Holland, 1941, p. 45).

The Rocky Mountains east of the northern section of the Trench are composed of what are believed to be dominantly lower Palaeozoic rocks, tightly folded and drag-folded and broken into westerly-dipping fault blocks. Here, the deformation seems to be due mainly to compression from the west (McConnell, 1896, p. 32; Hedley and Holland, 1941, p. 44), but no correlation with structures west of the Trench has yet been possible. East of the lower Kechika valley the formations trend obliquely into the Trench and are truncated by it (Hedley and Holland, 1941, p. 46).

Continental sediments of Paleocene age are found in, and are confined to, the floor of the Trench for a distance of 120 miles along the Finlay and Kechika valleys. These sediments have not been affected by the profound folding and faulting which have distorted the rocks of the Trench walls. They have, however, in places been slightly tilted and faulted into long narrow

ridges, parallel to the axis of the Trench. A well preserved longitudinal fault scarp, in the west side of the Trench floor along the upper Kechika valley, may indicate relatively recent adjustment of the floor.

HYPOTHESES OF ORIGIN OF THE ROCKY MOUNTAIN TRENCH

Dawson (1886, pp. 5, 28-31) was the first to recognize the Trench as an important feature of the North American Cordillera. He considered it to be an exaggerated "strike valley," eroded in Tertiary times by a southward flowing stream. Since then, almost every geologist who has examined the Trench has proposed a different hypothesis regarding its origin. While some of these hypotheses have since proved to be untenable, a number of apparently contradictory explanations seem to be based on carefully gathered data, and to apply reasonably well to those portions of the feature for which they were proposed.

It is apparent that the Trench is not a simple lineament with the same structural history in every part. The majority of the hypotheses advanced involve movement along faults parallel to the Trench, although Rice (1937, p. 32) has given evidence that, in the extreme southern part, such faulting does not seem to have been the dominant control in the location of the Trench. All workers agree that the Trench was an important valley feature at least as early as Eocene time, and some consider its main development was controlled by pre-Laramide crustal movements. There is agreement also that, at least north of Canal Flats, the structures of the mountains to the west are older than, and are truncated by, the structures of the Rocky Mountains (Schofield, 1913, p. 55). In addition, the structures east of the Trench between Canal Flats and Blaeberry, and along the Kechika Valley, are truncated by it.

THE TRENCH A GRABEN: DALY, 1912

From the occurrence of Precambrian rocks on its walls, and longitudinal faults down the east side bringing Devonian strata in the Trench into contact with Precambrian, Daly suggested (1912, p. 600) that the Trench may be a graben. He considered the faulting to be pre-Miocene, probably connected with a late relaxational phase of the Laramide revolution. Daly later withdrew his opinion that the fault in this sector might be a graben, and stated that nowhere in the south are there equivalent formations at the same level on both sides of the Trench (1915, p. 114).

THE TRENCH A TILTED, DOWN-DROPPED BLOCK: SCHOFIELD, 1921

Extending Daly's observations near the International Boundary, Schofield discovered a small reverse fault west of the Trench, and postulated that the Trench floor is a fault block, which was dropped as a unit and tilted along a longitudinal axis near its western border. Thus the east side was thrown down, bringing Devonian strata against Precambrian, while the west side was thrust upward a short distance (1921, p. 75).

THE TRENCH ALONG A ZONE OF FAULTING OF GREAT VERTICAL DISPLACEMENT: DALY, 1915

From his studies in the Golden area, Daly suggested that the Trench might be localized along a master fault along its west side. He considered the movement on this fault to have been normal, with a downthrow to the northeast of at least 20,000 feet (1915, p. 113). However, Drysdale (1917) and others have shown that the supposed Precambrian strata west of the Trench in this area include rocks actually younger than the early Palaeozoic rocks in the Trench floor. The likelihood, therefore, is that Daly misinterpreted the structure of the Selkirks, which are structurally separated from the Dogtooth Mountains. Daly's fault appears to be a westerly-dipping overthrust.

THE TRENCH ALONG A MAJOR TRANSCURRENT FAULT: DALY, 1915

Daly considered that the great length, straightness, and narrowness of the Trench, its presence in rocks of many types and ages, and the absence of rocks of equivalent formations at the same level on both sides, combine to suggest that it is the locus of a great transcurrent fault of the San Andreas type (1915, p. 114).

No points from which a major offset could be measured have been recognized along the Trench, and Rice (1937, p. 32) has shown that transverse faults on each side of its southern part appear to be in line.

Remnants of major transverse stream valleys, thought to have been developed at least as early as Miocene time, appear to be continuous across the Trench.

THE TRENCH DEVELOPED ALONG A ZONE OF INTERSECTING THRUST FAULTS: SHEPARD, 1922B

Shepard studied the intense faulting on both sides of the Trench. He noted that in most places the folds are overturned toward the Trench, and their axes dip away from it. Such a fold pattern would tend to produce a depression. He interpreted the faults as thrust faults essentially parallel to the axial planes of the folds. In all studied examples, the westerly-dipping thrusts on the west side of the Trench cut the easterly-dipping thrusts on the east side (1922A, p. 135). Shepard postulated that in the Windermere area (Section C) the Trench was eroded along the intersection of two such thrust planes. Farther south these faults lie within the Rocky Mountains, and have not formed a valley.

THE TRENCH DUE TO EROSION BY AN ANTECEDENT STREAM: SHEPARD, 1922A

Shepard could find no evidence for structural control of that part of the Trench between Cranbrook and Windermere (Sections B and C), and considered the valley there to be cut by unaided river erosion. The Purcell Ranges, deformed in the Jurassic, are thought to have been peneplaned in the Cretaceous, and to have developed valleys out of accord with the structures produced by Jurassic mountain building. During the Laramide and later uplift, these streams maintained their courses. As evidence, Shepard pointed out that this section is the widest part of the entire Trench, and the only stretch over which the same formations, with approximately the same strike, are present on both sides (1922A, p. 137).

THE TRENCH A FAULT-LINE VALLEY: SHEPARD, 1922A

From Cranbrook to the International Boundary, the fault along the east side of the Trench, mapped by Daly and Schofield as a normal fault (Sections A and B), was considered by Shepard to be a thrust. He suggested that the trench valley developed by erosion along this fault plane (1922A, p. 139).

THE TRENCH ERODED ALONG THE EDGE OF CAMBRIAN TO DEVONIAN SEAS: DALY, 1912; WALKER, 1926

Daly noted that the western edge of the lower Palaeozoic Rocky Mountain geosyncline was roughly parallel to today's Trench, and was not far to the west of it. He suggested that the line of dislocation marked by the Trench may have been genetically related to the contrast of rigidity between the strong Precambrian rocks, reinforced by abundant intrusions, to the west, and the relatively weaker geosynclinal sediments (1912, p. 199).

Walker observed that the Palaeozoic formations exhibit rapid thinning to the west, and suggested that the deformation may have been greatest along the Palaeozoic-Precambrian contact, with the Trench subsequently eroded along the deformed zone (1926, p. 40). This westward decrease in thickness was interpreted by Evans (1933, p. 170) as signifying that the area to

the west of the Trench was positive during much of Palaeozoic time, while that to the east was negative, producing an inherited line of weakness in the basement rocks, which might then have been reflected during later deformation.

THE TRENCH A HORST: SHEPARD, 1926

Shepard found Lower Ordovician rocks in the floor of the Trench, Upper Ordovician to the west, and Silurian to the east, and postulated that the Trench is a horst, which by long-continued erosion has been transformed from an uplifted area into a depression (1926, p. 640). No later evidence has come forth in support of this view, and there is considerable evidence against it.

THE TRENCH ALONG A ZONE OF REPEATED VERTICAL FAULTING: SCHOFIELD, 1921

From a study of the drainage sequence of the eastern Cordillera, as reflected in the present physiography and the distribution of late Cretaceous and Tertiary sediments, Schofield concluded that parts of the Trench were developing as subsequent valleys, along the eastern boundary of the Purcell-Selkirk mountain mass, in late Cretaceous time (1921, p. 92). Normal faulting in Eocene time produced a depression along the line of the southern section of the Trench, interrupted the courses of transverse rivers, and diverted their streams southward along the Trench. Post-Eocene faulting completed the interruption, and caused complete separation of the drainage of the northern and southern sections of the Trench (p. 97). Schofield considered the entire northern section of the Trench to be a subsequent valley (p. 95).

THE TRENCH A DEPRESSED AREA BETWEEN AN OVERTHRUST AND AN UNDERTHRUST: EVANS, 1933; LINK, 1935

Evans studied the Trench and its surroundings in greater detail than any other worker to date. He mapped a series of westerly-dipping thrust faults on the west side, and easterly-dipping thrusts on the east side (Section E). He interpreted the deformation of the Selkirk and Purcell Mountains as due to pressure from the west in late Jurassic or early Cretaceous time, producing the north-striking structures in essentially their present form. Upon recommencement of pressure from the southwest in Laramide time, the compacted, deformed Selkirks and Purcells were little affected, and transmitted the pressure to the sediments of the Rocky Mountain geosyncline, causing underthrusting on the east side of what is now the Trench, and resultant overturning to the southwest. The Trench line was affected by both orogenies and developed into a highly deformed linear zone, along which later erosion could easily work (1933, p. 167).

On much the same structural evidence, Link proposed that the east-dipping thrusts on the east side of the Trench meet a low-angle west-dipping thrust at depth, so that the east wall has been relatively lifted as a wedge, and the Trench relatively depressed by a modified ramp action, due to compressive forces from the southwest (1935, p. 1466). For the Montana section of the Trench, Clapp (1932, p. 19) believed that the steep east-dipping thrusts are older than, and are therefore presumably cut by, the low-angle west-dipping thrusts.

THE TRENCH NOT ALONG THE EDGE OF THE LARAMIDE DEFORMATION, NOR ALONG A FAULT LINE: RICE, 1937

From the Cranbrook area, Rice recorded faults, believed to be of early Cretaceous or earlier age, that line up across the Trench without offset. In this area the zone of weakness between the Nevadan and Laramide structures leaves the Trench and enters the Rocky Mountains, where it does not control the topography (1937, p. 31). Rice could not reach any conclusion as to the origin of the Trench.

THE TRENCH ALONG A LINE OF "LATERAL" FAULTING: HEDLEY AND HOLLAND, 1941.

In the Kechika valley, latitude 59° N., the northern ends of the structures in the Rocky Mountains are truncated at an angle of about 10 degrees by the Trench; the southeastern ends of the Cassiar structures, which lie west of the Trench, at about 25 degrees. Attempts to correlate structures or formations across the Trench have been unsuccessful, but the general structures are interpreted as due to compression from the southwest. Hedley and Holland concluded that the Trench represents a line of repeated "lateral faulting," or combined folding and faulting parallel to its axis (1941, p. 46). Most of the deformation must have taken place before the Paleocene sediments were laid down in the valley floor, but there has been a small amount of adjustment since that time.

THE TRENCH PART OF A NORTH TRENDING "RIFT ZONE" IN THE ROCKY MOUNTAINS: EARDLEY, 1947A

Eardley has pointed out that a series of trenches extends from north-central Arizona to the Rocky Mountain Trench, forming a belt nearly 2,000 miles long. He suggested that there may be a genetic connection between the southern trenches, most of which are believed to be graben or rotated-block structures superimposed on Laramide folds and genetically related to them, and the Rocky Mountain Trench. Except at the two extremities, however, the Trench is not known to be discordant to Laramide structures, and it seems not to be a graben. The southern belt of faults may represent a rift zone (1947A, p. 1176).

THE TRENCH CHARACTERIZED BY CLOSELY SPACED, PARALLEL, STEEPLY DIPPING FAULTS: ROOTS, 1954

In the Aiken Lake map-area the Trench is apparently characterized by closely spaced, parallel, steeply-dipping faults, along which the movement has been mainly vertical. Long narrow slices of the Paleocene Sifton formation have been lowered into the present valley floor. Stratigraphic relations suggest the possibility that the amount of this down-faulting may be tens of thousands of feet. The southwest wall of the Trench in this area appears to be a fault scarp or fault-line scarp, exposed over a vertical depth of about 1500 feet.

PRESENT AUTHORS' HYPOTHESIS

There is clearly ample scope for comment on the origin of the Trench. At the present time, there appear to be two sharply contrasted schools of thought concerning it. The first holds that the Trench, at least from about Radium northward, is controlled by a master fault or fault-zone along its floor. This appears to be the view of the compilers of the Tectonic Map of Canada. The second school maintains that the Trench is strictly an erosional feature, largely if not wholly independent of faulting, though faults may appear in or near it incidentally.

On purely polemical grounds, the hypothesis of fault control for the Trench is so immediately obvious that it seems fair to place the onus of argument on those who deny it. There may be no other feature on the earth's surface really comparable with this Trench, but others remotely similar to it are regarded as being controlled by the great faults of the world. Every geologist will be able to think of examples, from the Jordan Valley and the Great Glen to the Champlain-Logan line and the Peru-Chile submarine trench. Apart from some constructional shorelines, all long straight physiographic features are characterized by faulting. When dealing with such a feature in an area which is completely dominated by faulting, it seems futile to look for an origin for it independent of faulting.

Any attempt to explain the Trench must account in a logical manner for its three fundamental characteristics: its great length and essential linearity; the fact that it truncates the structures immediately flanking it *on both sides*; and the fact that it brings into juxtaposition, over at any rate a great proportion of its length, two completely separate geological provinces.

These features can only be accounted for by faulting, and faulting on a continental scale. The amount of crustal shortening across the Trench must be greater than has ever been suggested for any Cordilleran fault except the Lewis overthrust. Whether the shortening was brought about by thrusting, or by transcurrent faulting, or by a combination of both, is not known. There is some evidence bearing on the question, however, and this will be offered later in this paper. The net result has been a linear feature of such remarkable apparent simplicity that one is forced to the conclusion that the controlling structures must be basically very simple. The complexities are details superimposed upon this basic simplicity. Thus the commonly held present-day view that the Trench has had a complex structural history, probably quite different in different parts, may be very misleading. Though no doubt an important reservation containing elements of truth, it may also, in our opinion, obscure the real truth.

We will illustrate our theory on the fault control of the Trench by treating in detail the stretch between Blaeberry and the International boundary. This stretch is crucial for two reasons. Firstly, it is far from straight, so that the fault control within it is not immediately obvious. Secondly, it includes the Cranbrook-Kimberley portion, in which Rice (1937, pp. 31-2) mapped large transverse faults apparently crossing the Trench almost at right angles without offset. We will try to account for these features by demonstrating three points:

(1) That the sinuous Trench between Blaeberry and Canal Flats is controlled by a major thrust-fault, or fault-zone, which marks the forward boundary of the Purcell Range.

(2) That the Trench between Blaeberry and Bush Lakes, and possibly northward from there, is straight because the younger White River Break was superimposed upon the older Purcell thrust-fault. This linear fault control leaves the present Trench at Blaeberry, and extends southeastward along the line of the present trace of the White River Break (see p. 38).

(3) That the Purcell front itself leaves the Trench about at Canal Flats, and thence southward is east of the Trench. The present physiographic Trench south of Canal Flats may be quite without fault control; it is simply a river valley.

The transverse faults mapped by Rice are presumed to be of the same age as those in the Hughes and Galton Ranges. In observed cases these are younger than the longitudinal faults, and offset them, so that they might also cross a longitudinal trench fault without offset. Where the zone of transverse faulting is entered, about at Canal Flats, the identity of the physiographic Trench becomes less clearly defined; neither the regular form nor the characteristic trend continue to the south. There is a thick blanket of gravel and silt over a width of ten miles, and the real walls are 17 miles apart at Kimberly. At no point southward from Kimberley to its presumed southern limit at Kalispell, has the Trench the appearance it has, for instance, along the Big Bend highway. Some block-faulting is no doubt present near the boundary, and some of it may assist in localizing the Trench in places. But there is no suggestion here of a major fault control like that farther north.

Northward from Canal Flats, every aspect of the Trench suggests an origin subsequent upon faulting, and at no point is it *known to be unfaulted*. The fact that some of the known faults are not quite parallel to the Trench is not in itself a problem; even under control by a single vertical fault, there is no reason why a fault-line scarp must be exactly parallel to the fault. In the case of a valley eroded along a complex zone of overlapping thrust faults, the resulting valley line is not likely to be parallel to any one fault for more than a short distance. The Trench between Blaeberry and Canal Flats separates ranges characterized by overturning of structures towards it. Within this sector, the largest observed fault entering the Trench is the Redwall fault, and it is essential to any study of this stretch of the Trench to determine whether this fault crosses it or not. Its trace appears to be continuous, in a straight line, from east of Radium into the Trench between Harrogate and Jubilee Mountain, and thence along the

east face of the Dogtooth Mountains. However, if this continuity is real, the fault must change along the strike from being a transcurrent fault (in the Stanford Range) to being a northeastwardly directed thrust fault (in the Dogtooths). It must also change from bounding, to the east, a belt of rocks overturned towards the *west*, to bounding a belt overturned towards the *east*. These changes are highly improbable. The fault at the front of the Dogtooth Range is much more likely to be separate from, and younger than, the Redwall fault. As a thrust-fault, it must either transect or override the northwesterly continuation of the Redwall fault. The point of transection cannot be further north than Harrogate; it is likely to be between Edgewater and Spillimacheen.

Interesting evidence on this point is afforded by the distribution of the brachiopod species *Spirifer argentarius and Spirifer engelmanni,* both now commonly assigned to the genus *Acrospirifer*. All outcrops of the very fossiliferous upper Harrogate formation are in general distinguished by the same Middle Devonian brachiopod fauna. However, the most fossiliferous of all occurrences—those in the Stanford and Brisco Ranges— do not carry the genus *Acrospirifer,* whereas some much less fossiliferous outcrops do carry it. It has so far been found in four localities—on Mount Forster; at the mouth of Sinclair Canyon; on Gold Creek (southeast of Cranbrook); and at Roosville (on the Tobacco Plains at the International Boundary). In the first, third and fourth of these localities, the Devonian beds either rest directly on Precambrian rocks, or are separated from them by only a very small interval. Moreover, all these three localities are either within the Trench, or west of it. They belong, that is, essentially within the Purcell system rather than within the Rocky Mountain system. The brecciated limestone in Sinclair Canyon is stratigraphically useless, having no unfaulted contact with any other formation. Like the Roosville outcrop, it appears to be inverted. The presence in it of *Acrospirifer,* however, suggests the possibility that the outcrop rested originally on the Precambrian, or was separated from the Precambrian by a very small interval. It may, in other words, belong within the Purcell system, and it may now lie west of the fault fronting the overriding Purcell block.[1] If this is the case, one fault in the Trench farther south, which converges northward with the Redwall fault, lies immediately west of the road-cut in Sinclair Canyon. The fault between Jubilee Mountain and the Brisco Range would then be this fault, a major overthrust from the west, rather than the Redwall fault.

Farther north, the same fault lies on the other side of the Trench, at the foot of the Dogtooth Mountains. To the south, at Windermere Lake, the presence of outcrops of the Upper Cambrian Jubilee formation in the floor of the Trench, combined with the structure at the eastern edge of the Purcell Range (section C - C'), strongly suggests a westerly dipping thrust fault in the Trench, probably under the lake. Either another fault, or the southerly continuation of the same one, is reasonably inferred west of Fairmont Hot Springs, where Purcell sediments form the west wall, dipping west, and a faulted sequence of Upper Cambrian and Upper Ordovician limestones strikes almost directly into the Trench on the east wall. Along Columbia Lake a fault is incontestable, with the west side again raised. A zone of shearing, seen on the west wall near Canal Flat station, may represent this fault. It may be a north-westerly continuation of a fault in the Hughes Range, or one lying entirely within the Trench.

Whether these fault occurrences all represent the same fault, or different members of a fault-zone, is not known. However, it is apparent that the zone effectively marks the eastern front of the Nevadan Purcell and Dogtooth Ranges, and that it must be a zone of thrust-faulting. Thrust fronts are seldom very straight for any long distance, and nowhere between Blaeberry and Canal Flats is the Trench as continuously straight as it appears to be on a small scale map. Its trend varies between north 55 degrees west and almost due north-south. It typically follows

[1] This is not affected by the distribution of the *Spirifer jasperensis* fauna of the Flume formation, described by Warren (1942, pp. 129-136). The two species occurring in the Western Ranges sub-province appear to have the restricted distribution indicated here.

a remarkably straight course for a short distance—say ten miles—and then after a rather abrupt turn follows another short straight course before a further turn. These turns may be in either direction; many of them are small in angle—about ten degrees—but turns of up to thirty degrees are known. At about Fairmont Hot Springs, for instance, the course of the Trench changes from almost due north to north 30 degrees west. Eight miles southeast of Golden, there is a further turn, again of about thirty degrees, but in the opposite direction. This pattern is characteristic of many of the world's greatest faults—the San Andreas fault, for instance, or the West Bay fault near Yellowknife, or the African rifts.

On these terms, the northwesterly plunging structures of the western ranges of the southern Rocky Mountains have been over-ridden from the west by those of the Purcell and Dogtooth Ranges. From Blaeberry northward, however, the Purcell structures are themselves truncated by younger faults, including the White River Break. There are, in fact, both Jurasside and Laramide lineaments in the present Trench; it does not everywhere separate structures of the two deformations from one another. Even south of the Big Bend of the Columbia, we have a peculiar, three-fold, structural division for the Trench:

(1) From the Big Bend to Blaeberry, the Trench is very regular and almost straight. It certainly appears here to be a true "Rocky Mountain feature," and also to be the bounding zone between the Rocky Mountain and the Interior systems of mountains.

(2) From Blaeberry to Canal Flats, the Trench comprises the belt of minor turns described above, and as a "bounding belt" it is transitional. The mountains on the west, including the Dogtooths and the intravalley ridges, show many features in contrast with those of typical Purcell or Selkirk mountains. Those on the east, the Western Ranges subprovince of the Rocky Mountain system, likewise differ conspicuously from the remainder of the Rocky Mountains.

(3) From Canal Flats to Flathead Lake, the Trench is poorly defined and has Interior Range (or Purcell) stratigraphy on both sides of it. It also has structures on both sides of it (the transverse faults) which are less common elsewhere in the Rocky Mountains.

TYPE OF FAULT CONTROL

Daly's analogy between the Trench and the San Andreas fault would require the former to be controlled dominantly by transcurrent or strike-slip faulting. The strongest evidence in favour of this hypothesis is the truncation of structures *on both sides of the Trench*. That large strike-slip faults are present, in the immediate area of the Trench, has been proven; the Redwall fault is a vertical fault with sinistral transcurrent movement of at least five miles, and it is known to enter the Trench, very slightly obliquely, shortly north of Sinclair Creek.

But there is also very powerful evidence *against* large-displacement transcurrent faulting. The minor changes of direction, which appear to favour it, are superimposed upon a pattern involving two *major* changes of direction—those at the two "breaks" in the structure of the Trench. The pattern as a whole is not indicative of transcurrent faulting. Moreover, the transcurrent zone would need to be in virtual coincidence, for 1,000 miles, with the boundary between two geological provinces, and there is nothing to indicate why this boundary should be so abrupt or so straight. The bulk of the stratigraphic evidence is also against transcurrent faulting on a large scale. All pre-Chazy formations are represented, in an understandable manner, on both sides of the Trench, and on both sides of the White River Break.

The fact that the Trench is largely in coincidence with the front of the Purcell Range, in the stretch south of the Big Bend of the Columbia, is *prima facie* evidence in favour of its control by thrust-faulting. This control accounts for the crustal shortening; for the fact that the Trench apparently separates two geological provinces; and for the truncation of the structures on either

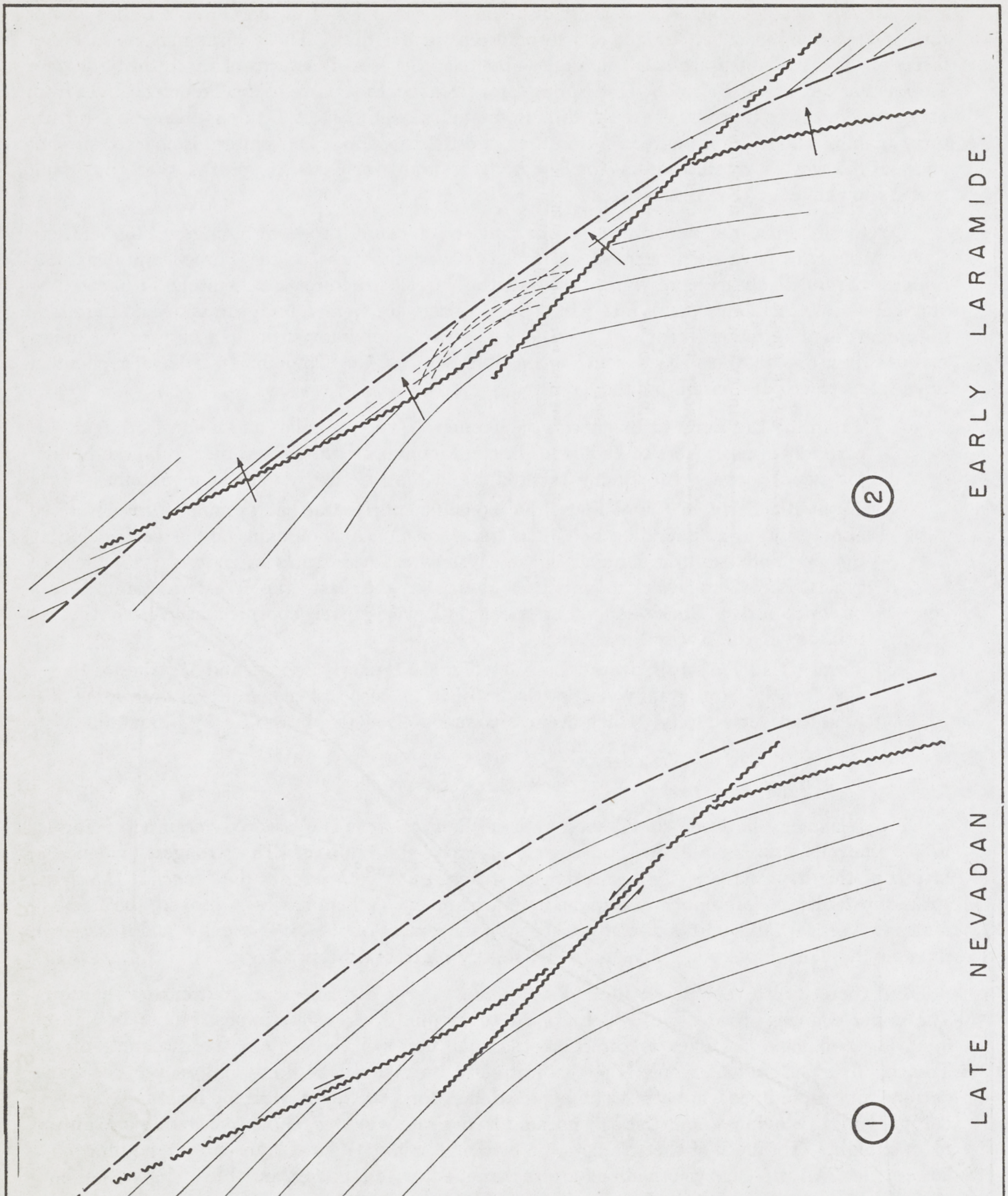


Figure 4a

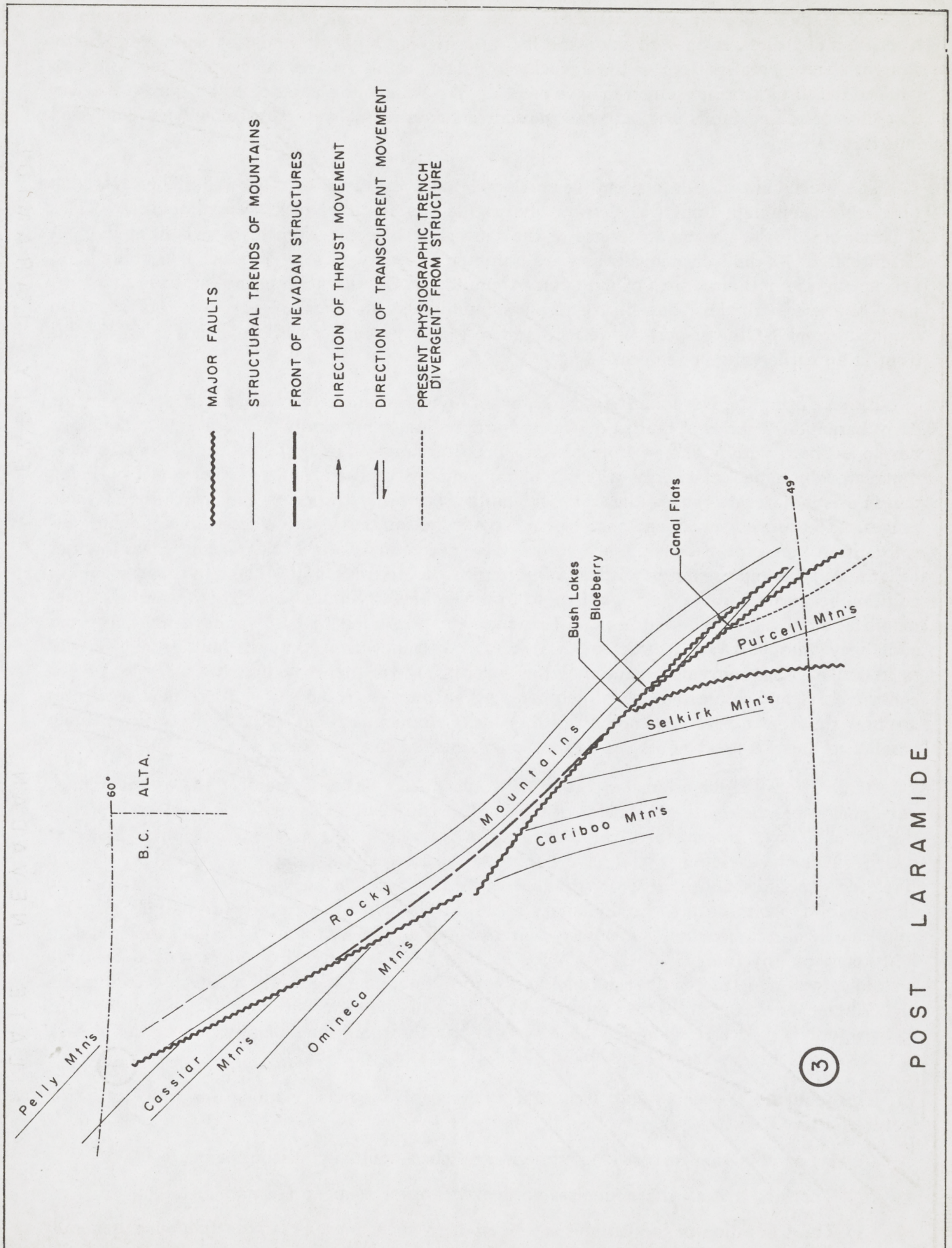

MAJOR FAULTS
STRUCTURAL TRENDS OF MOUNTAINS
FRONT OF NEVADAN STRUCTURES
DIRECTION OF THRUST MOVEMENT
DIRECTION OF TRANSCURRENT MOVEMENT
PRESENT PHYSIOGRAPHIC TRENCH DIVERGENT FROM STRUCTURE
Canal Flats
Blaeberry
Bush Lakes
49°
Purcell Mtn's
Selkirk Mtn's
Rocky Mountains
Cariboo Mtn's
Omineca Mtn's
Cassiar Mtn's
Pelly Mtn's
60°
B.C.
ALTA.
3
POST LARAMIDE

Figure 4b

one side or the other. It is less satisfactory than the transcurrent fault hypothesis in explaining truncation of structures on *both* sides, and it is unusual for a thrust fault to be so persistently straight (the general pattern of the Trench is, in fact, convexly arcuate towards the direction whence the thrusts are presumed to have come). We believe the paradox to be due to the fact that the controlling faults originated as transcurrent faults, but were later effectively converted into thrusts.

The mechanics of this process we envisage more or less as follows. The Nevadan (Jurasside) mountain front was presumably originally arcuate, convex towards the east. This is borne out by the present structures of the ranges west of the Trench, now truncated by it (Figure 4a). As the front moved eastward, some structures would be produced in front of it, akin to the foothills structures of most folded mountains. On relaxation of the Jurasside thrusting, some of these "wrinkles," possibly themselves faulted, would remain east of the Nevadan mountain-front. Others, perhaps formed rather earlier, would have been over-ridden by this front at an earlier stage of the thrusting.

Either during the Nevadan movements, or on revivification of the Nevadan structures in the early Laramide, a series of faults developed more or less tangentially. These faults doubtless developed both within, and in front of, the Jurasside ranges, but those within the ranges were dominated by a pair of enormous, straight, tangentially-disposed faults (Figure 4a). Being *within* existing arcuate ranges, these straight faults necessarily truncated the structures of these ranges. The movement along them would have to be transcurrent, the west sides moving outwards from the point of convergence, in order to accommodate the advancing Purcell front (Figure 4a). A representative of this fault-group is the Redwall fault. The movement would in addition be greatest in the centre, dying out towards the forty-ninth and sixtieth parallels. Remobilization of the whole belt, in main Laramide time, resulted in both faults being converted effectively into eastwardly-directed thrust-faults, with movement on each fault at right angles to its strike. This movement caused further over-riding of the structures to the east of the control faults, and so created new structures lying yet further to the east. These new structures are now the front ranges and foothills of the Rocky Mountain system, and they are approximately parallel to the two great faults whose movements helped to raise them.

As the control faults originated *within* the Nevadan ranges, a segment of these ranges must have been separated on the east sides of the faults. During the Laramide movements, a part of this segment was presumably over-ridden from the west by the new moving front. That part which was not over-ridden would have Laramide structures superimposed upon pre-existing Jurasside structures, and both these structures would be in older rocks—largely Precambrian, in all probability, as the exposed sedimentary series in the Nevadan ranges are largely of Precambrian age. Hence there is now a belt of rocks on the *east* side of the Trench, extending fairly continuously from Hamber Provincial Park to Fox River, which is characterized by three features: great age (mostly Precambrian and early Cambrian); highly complex structures; and a high degree of metamorphism. Such superposition of one set of structures upon another, due to two periods of deformation, has been observed in the rocks immediately east of the Trench in the Kechika River sector (Hedley and Holland, 1941, pp. 38, 45).

This sequence of events would account in a reasonably logical manner for the following features of the Trench:

(1) Its combination of two long, straight stretches, mutually discontinuous.

(2) The fact that all the structures west of it appear to be pre-Laramide.

(3) The truncation of the structures west of it in such a way that the following generalization can be made. The trend of the greater part of the *southern* section of the

Trench, between Blaeberry and the Big Bend of the Fraser River, is about the same as the strike of the Omineca and Cassiar structures, west of the *northern* section of the Trench. This strike is almost due northwest. The trend of its northern section, from the "first break" to the Liard River, is about the same as the strike of the Nevadan structures west of its southern section (including the Purcell Trench). The eastward projection of these now divergent structures produces the original arcuate form of the Nevadan mountain front (Figures 4a, b).

(4) The truncation of the structures to the east of the Trench, particularly at the north and south extremities, at relatively small angles.

(5) The approximate parallelism of the whole Trench to the front ranges of the Rocky Mountains, and to the McConnell fault. This parallelism is seen also, perhaps significantly, in the east margin of the Coast Range batholith.

(6) The fact that the Rocky Mountain system is concave towards the apparent direction of Laramide movement.

(7) The presence of a segment of ancient, metamorphic rocks on the east side of the Trench in its central portion, narrowing towards the two extremities.

(8) The great crustal shortening across the Trench.

Why the original controlling faults developed in the manner they did we do not yet understand. Nor have we so far accounted for the linear structural zone being now represented by a physiographic Trench. This can only have been brought about by river erosion. The original drainage in the proto-trench would follow the approximate position of the fault-line scarp of the Purcell front, southward until the structures of the Brisco and Stanford Ranges diverged from below this front. The drainage was probably then in part subsequent upon these structures, in part conformable with the thrust-front. The subsequent history of the Trench south of Blaeberry may be simply that of steady westward shift as the fault-line scarp of the Purcell front was eroded back. The abrupt, low-angle turns in the course of the Trench over this part are probably the result of the drainage taking advantage, over short distances, of fault-planes of the Western Ranges structural sub-province, exposed by erosion as the thrust-front was driven back. The late Laramide movement along the White River Break straightened the course of the Trench between Blaeberry and Bush Lakes, but it is significant that the main drainage between these two points is not in the Trench. Erosion had already driven the Purcell front farther to the west before the White River Break was formed.

BIBLIOGRAPHY

Andrews, G. S. (1942): Alaska Highway Survey in British Columbia; Geogr, Jour., vol. 100, pp. 5-22.

Armstrong, J. E. and Tipper, H. W. (1948): Glaciation in North Central British Columbia; Am. Jour. Sc., vol 246, pp. 285-6.

Bostock, H. S. (1948): Physiography of the Canadian Cordillera etc.; Geol. Surv., Canada, Memoir 247.

Burling, L. D. (1922): The Relations between the Purcell Range and the Rocky Mountains in British Columbia; Am. Jour. Sc., ser. 5, vol. 3, pp. 254-5.

Calkins, F. C. (1909): Geological Reconnaissance in Northern Idaho and Northwestern Montana; U.S.G.S. Bull. 384, pp. 7-91.

Clapp, C. H. (1932): Geology of a portion of the Rocky Mountains of Northwestern Montana; Montana Bur. Mines and Geol., Memoir No. 4.

Coleman, A. P. (1890): Notes on the Geography and Geology of the Big Bend of the Columbia; Trans. Roy. Soc. Canada, vol VII, pp. 97-108.

Daly, R. A. (1912): Geology of the North American Cordillera at the Forty-ninth Parallel; Geol. Surv., Canada, Memoir 38.

(1915): Geological Reconnaissance between Golden and Kamloops, British Columbia; Geol. Surv., Canada, Memoir 68.

Dawson, G. M. (1886): Physical and Geological Features of the Rocky Mountains; Geol. Surv., Canada, Ann. Rept. 1, 1885.

Dolmage, V. (1928): Finlay River District, British Columbia; Geol. Surv., Canada, Summ. Rept. 1927, A, pp. 19-41.

Drysdale, C. W. (1917): Investigations in British Columbia; Geol. Surv., Canada, Summ. Rept. 1916, A, pp. 44-63.

Eardley, A. J. (1947A): Late Cenozoic Trenches of the Rocky Mountains; Bull. Geol. Soc. Amer., vol. 58, p. 1176.

(1947B): Paleozoic Cordilleran Geosyncline and Related Orogeny; Jour. Geology, vol. 55, No. 4, pp. 309-342.

(1951): Structural Geology of North America; Harper's Geoscience Series, pp. 303-4.

Evans, C. S. (1933): Brisco-Dogtooth Map-Area, British Columbia; Geol. Surv., Canada, Summ. Rept. 1932, A, pp. 106-176.

Hedley, M. S. and Holland, S. S. (1941): Reconnaissance of Turnagain and Upper Kechika Rivers; Brit. Col. Dept. Mines, Bull. No. 12.

Henderson, G. G. L. (1954): Geology of the Stanford Range; Brit. Col. Dept. Mines, Bull. No. 35.

Lay, D. (1941): Fraser River Tertiary Drainage-history; Brit. Col. Dept. Mines, Bull. No. 11.

Link, T. A. (1935): Types of Foothill Structure of Alberta, Canada; Amer. Assoc. Petrol. Geol., Bull. vol. 19, pp. 1427-1471.

McConnell, R. G. (1896): Report on Explorations in the Rocky Mountains; Geol. Surv., Canada, Summ. Rept. 1892, A, pp. 10-12.

(1893): Report on an Exploration of the Finlay and Omineca Rivers; Geol. Surv., Canada, Ann. Rept. vol. VII, pt. D.

McEvoy, J. (1900): Report on the Geology of the Yellow Head Pass Route; Geol. Surv., Canada, Ann. Rept. vol. XI, pt. D.

Malloch, G. S. (1910): Reconnaissance on Upper Fraser River between Fort George and Tete-Jaune Cache; Geol. Surv., Canada, Summ. Rept. 1909, pp. 123-130.

Mansfield, G. R. (1923): Structure of the Rocky Mountains in Idaho and Montana; Bull. Geol. Soc. Amer., vol. 34, p. 263.

Ransome, F. L. (1915): Tertiary Orogeny of the North American Cordillera and its Problems; Problems of American Geology, pp. 287-376.

Rice, H. M. A. (1937): Cranbrook Map-Area, British Columbia; Geol. Surv., Canada, Memoir 207.

Roots, E. F. (1954): Geology and Mineral Deposits of the Aiken Lake Map-Area, British Columbia; Geol. Surv., Canada, Memoir 274.

Schofield, S. J. (1913): Elko to Kootenay Lake, British Columbia; Guidebook No. 9, XII Int. Geol. Congress, pp. 46-61.

(1921): The Origin of the Rocky Mountain Trench; Trans. Roy. Soc. Canada, Ser. 3, vol. 14, Sec. 4, pp. 61-97.

(1923): The Geological Record of the Cordillera in Canada; Trans. Roy. Soc. Canada, Ser. 3, vol. 17, Sec. 4, pp. 79-103.

Schuchert, C. (1923): Sites and Nature of the North American Geosynclines; Bull. Geol. Soc. Amer., vol. 34, pp. 151-229.

Shepard, F. P. (1922A): The Structural Relation of the Purcell Range and the Rocky Mountains of Canada; Jour. Geol., vol. 30, pp. 130-139.

(1922B): Problems in Stratigraphy along the Rocky Mountain Trench; Jour. Geol., vol. 30, pp. 361-376.

(1926): Further Investigations of the Rocky Mountain Trench; Jour. Geol., vol. 34, pp. 623-641.

Walker, J. F. (1926): Geology and Mineral Depoists of Windermere Map-Area; Geol. Surv., Canada, Memoir 148.

Warren, P. S. (1938): Age of the Selkirk and Rocky Mountains Uplifts in Canada; Am. Jour. Sc., ser. 5, vol. 36, pp. 66-71.

(1942): The Spirifer argentarius Fauna in the Canadian Rockies; Trans. Roy. Soc., Canada, Ser. 3, Vol. 36, Sec. 4, pp. 129-136.

INDUSTRIAL MINERALS IN THE SOUTHERN CANADIAN ROCKY MOUNTAINS[1]

J. W. McCAMMON[2]

INTRODUCTION

Few varieties of industrial minerals have been reported from the southern Rocky Mountain Region. Exploration work and mapping have been carried out on deposits of barite, gypsum, phosphate rock, and talc, in British Columbia. Only barite and gypsum have been produced commercially. Although large quantities of limestone and dolomite are available the locations of the deposits prevent them from being of economic interest to-day. In Alberta, however, limestone is quarried for cement manufacture by Canada Cement Company at Exshaw, and for quicklime and other lime products by Loder's Lime Company at Kananaskis, and Summit Lime Works at Crowsnest Pass. There is some nepheline syenite of the Ice River Complex lying outside National Park boundaries, but apparently it is beyond economic limits of access at present.

BARITE

Barite is common in the Rocky Mountain Trench area. It is found alone and as gangue in metallic deposits. Apart from one small shipment from a prospect on Phillips Creek, east of Flagstone, all commercial production has come from the Mountain Minerals Limited quarries near Parson and Brisco.

The Parson deposit is 5½ miles southwest of Parson siding. At the quarry barite is found in two parallel, irregular, steeply dipping fissure veins, that cut diagonally across quartzites, shales, and dolomites, which are thought to be of early Cambrian age. The rock series, apparently in the east limb of a major syncline, strikes northwesterly and dips steeply to the southwest. The veins are exposed for lengths of 150 and 200 feet and their widths pinch and swell from 1 foot to 30 feet. Small amounts of pyrite, quartz, limonite, and copper stains accompany the barite in the veins. Minor movement has taken place along the vein fissures since the ore was deposited.

The Brisco quarry is 2½ miles west of Brisco station. At this quarry barite forms a vein-like mass in a breccia zone in Ordovician dolomite. The breccia zone is probably related to a major southwesterly dipping thrust fault that extends northwesterly from the north end of Steamboat Mountain. Along the footwall the barite mass is brecciated and the matrix, essentially barite, is impregnated with finely divided, black, carbonaceous matter. Other impurities present in the deposit include silica, dolomite, and pyrite.

Several small barite deposits are known in the Stanford Range but little or no development work has been done on them. In all cases the barite appears to be hydrothermal and is associated with minor amounts of copper and lead minerals.

As gangue, barite is common with copper and lead mineralization in numerous deposits on Jubilee and Steamboat Mountains, and in showings on Horsethief and Toby Creeks. The most important occurrence is at the Silver Giant mine, where investigations have been made as to the feasibility of producing barite as a by-product.

CLAY AND SHALE

Bricks are reported to have been made in the past at Windermere and Fernie, but to-day no clay working plants are operating in the area. No high-grade clays or shales are known in the region.

[1] See map, page 117.
[2] British Columbia Department of Mines.

GYPSUM

Large gypsum deposits have been found on Windermere Creek in the Stanford Range, and along the Kootenay River, 8 to 10 miles northeast of Canal Flats. Small deposits are known 2½ miles above the mouth of Bull River, and on the west side of the Trench at Mayook siding, and in Chipka Creek, south of Wardner. It is interesting to note that the immense primary beds of rock gypsum in the Stanford Range were not recognized until 1947 although the Bull River, Mayook, and Chipka Creek deposits were found in the early 1920's, and Walker reported gypsite in sink holes on Windermere Creek in 1926.

The gypsum in the Stanford Range is part of the mid-Silurian to mid-Devonian Burnais formation. Beds of gypsum from 100 to greater than 600 feet in aggregate thickness are interstratified with limestone, thin beds of limestone-gypsum breccia, and scattered beds of carbonaceous shale. The gypsum rock is fine grained, well bedded, and finely laminated as alternate tan, grey, and white bands. Superficially is resembles limestone. An absence of anhydrite and of the laminar corrugations typically ascribed to expansion folding, and the presence of slump structures, minor penecontemporaneous faults that affect only a few laminae, and cross-bedding, together with the bedded nature of the deposits suggest that this gypsum is of primary sedimentary origin.

At least seven separate deposits of gypsum are known. Six of these are in downthrown blocks, and the seventh lies in a faulted syncline. Of the seven occurrences three are economically accessible, and it is estimated they contain in excess of 500 million tons of commercial gypsum available by quarrying.

The deposit on Windermere Creek is the best known and is the second largest in the area. It is the only one now being mined. Here the Burnais formation lies near the surface in an area of 6 square miles. Good exposures of gypsum are scarce, the best being at the quarry of Columbia Gypsum Products, Inc. At the quarry a stratigraphic thickness of nearly 500 feet of gypsum can be seen. The lower 300 feet are poorly laminated, iron stained, material which is 80 to 90 per cent gypsum. This is overlain by a member, 50 feet thick, of alternating limestone and gypsum. On top of this limy band are 115 feet of rock with an average content of 92 per cent gypsum. Carbonate is the chief impurity, accompanied by less than 1 per cent of silica, carbon, alumina and iron. Commercial production comes from the top high-grade layer. The powdered product is greyish and so cannot be used in finish plaster, but it is satisfactory in other phases of the gypsum industry. Mining began in 1949 and production reached an annual rate of 60,000 tons by the end of 1953.

In the Kootenay River Valley the Burnais formation is found near the surface over an area of more than 7 square miles. Gypsum crops out at numerous places throughout this area. One ¾ mile long reach of the east bank of the Kootenay River is formed by continuous gypsum cliffs 10 to 220 feet high. On claims west of the river, diamond drilling has indicated a thickness of more than 400 feet of gypsum. However, except for one trial shipment the deposits have not been worked in this region.

The gypsum at Bull River, Chipka Creek, and Mayook, occurs interbedded with limestone similarly to that in the Stanford Range, but the grade is much lower and the deposits are small. According to Schofield the limestone associated with the gypsum is of Devono-Carboniferous age. Intermittent shipments of gypsum have been made from Mayook to the cement plant at Exshaw since 1926. One small trial lot was quarried at Bull River in 1937. There has been no development work done at Chipka Creek.

PHOSPHATE

In 1915 phosphate was discovered in the Rocky Mountain formation near Banff. During the following year Spence traced the phosphate horizon south to Tent Mountain, near Corbin. The phosphate zone thins from 2 feet thick north of Banff to a few inches at the south extremity.

Burgess and Telfer found four phosphatic beds near Crowsnest in 1925. These occur near the base of the Mississippian Banff shale, near the top of the Pennsylvanian Rocky Mountain formation, and at the base and higher in the Jurassic Fernie shale. The principal phosphate field corresponds to Crowsnest Coal Basin. Smaller phosphate zones underlie the Cascade Coal Basin, near Canmore, and small areas in the Flathead Valley.

The Mississippian phosphate occurs as a black oolitic layer and a nodular layer in shale, at the bottom of the Banff formation. Neither layer is thicker than a few inches. The phosphate outcrops west of Fernie and for about 20 miles north and south of Crowsnest.

In the Rocky Mountain formation Telfer found that the phosphate occurs in four ways; as amorphous cement in the uppermost few feet of sandstone of the formation, in nodules forming 10 to 25 per cent of beds as thick as 20 feet in the upper 100 to 200 feet of the formation, as a massive bed a few inches to 2 feet thick just under the top chert and quartzite bed of the formation (apparently the same zone traced by Spence), and as an oolitic bed a foot or two thick about 75 to 125 feet below the top of the formation.

In the Fernie shale one phosphatic zone lies along the bottom contact of the formation, and a second horizon is located 150 to 250 feet above the base. The contact zone consists of as much as 4 feet of oolitic phosphate. The higher horizon is a calcareous sandstone bed with many belemnites, and it contains in places oolitic phosphate and nodules.

Between 1927 and 1933 The Consolidated Mining and Smelting Company of Canada, Limited, investigated these deposits. Although they found the beds to be relatively widespread the grades were considered too low to be commercial at that time.

TALC

Steatite talc occurrences are known along the British Columbia-Alberta boundary west of Banff. Unfortunately the deposits lie within the limits of Banff and Kootenay National Parks and so cannot be mined at present.

One deposit is on the southeast slope of Mount Whymper, north of and 1,000 feet above the Banff-Windermere highway, 2 miles west of Vermilion Summit. The talc occurs as a number of small, irregular, and nonpersistent lenses, probably parts of a single distorted bed, enclosed in grey dolomite. The crude talc is compact and massive and, although pale yellow-green, grinds to a good white powder. Commonly, it is intergrown with coarsely crystallized dolomite. Quartz is a frequent associate.

There are two talc showings, one-half mile apart, at an elevation of 8,000 feet on the interprovincial divide at Redearth Pass. This is near the heads of Pharoah and Redearth Creeks, about 16 miles southwest of Massive station. On the Red Mountain claim talc occurs in beds 1 foot to 5 feet thick, near the base of a thick grey dolomite formation. In one exposure 10 feet of fairly clean talc underlies 60 feet of red-weathering, massive, mottled white and black, talc, which contains much pyrite. A 10 foot thick bed is exposed on the Gold Dollar claim. The talc on both claims is massive and steatitic, ranging in colour from deep bluish black to mottled cream and black. The black coloration is due to finely disseminated carbon. In 1944 about 7½ tons of rock was produced from this locality for use as "lava" talc.

REFERENCES

Barite

(1) Geol, Surv., Canada, Sum, Rept. 1925, pt. A, pp. 227, 228.
(2) Can. Dept. Mines, Mines Br. Pub. No. 570, p. 22.
(3) Min. of Mines, B.C., Ann. Repts., particularly 1947, 1952.
(4) B.C. Dept. Mines, Geology of the Stanford Range—To be published.

Gypsum

(1) B.C. Dept. Mines, Geology of the Stanford Range—To be published.
(2) Min. of Mines, B.C., Ann. Rept., 1921, 1924, 1947, 1948, 1950.
(3) Can. Dept. Mines, Mines Br. Pub. No. 714, pp. 64-68.

Phosphate

(1) C.I.M.M. Trans., Vol. XXXVI, 1933, pp. 566-605.
(2(Min. of Mines, B.C., Ann. Repts., 1926-1933.
(3) Dept. Mines, Ottawa, Mines Br. Sum. Rept. 1916, pp. 24 to 34.
(4) Dept. Mines, Ottawa, Mines Br. Pub. No. 385.
(5) Dept. Mines, Ottawa, Mines Br. Pub. No. 396, pp. 104, 105.

Talc

(1) Can. Dept. Mines, Mines Br. Pub. No. 803, pp. 57-61.

CROSS-SECTION THROUGH THE CLARKE RANGE OF THE ROCKY MOUNTAINS OF SOUTHERN ALBERTA AND SOUTHERN BRITISH COLUMBIA

L. M. CLARK[1]

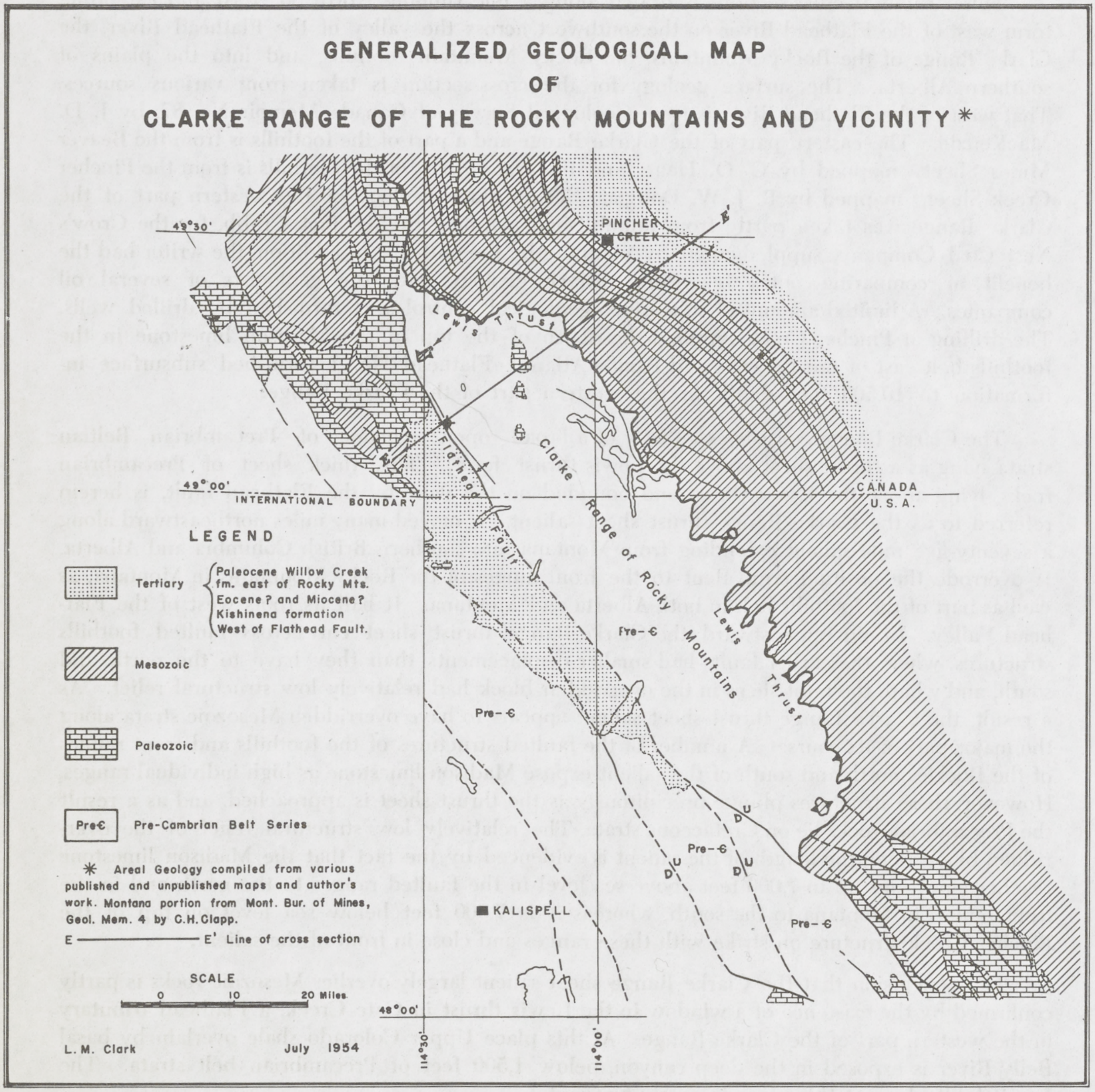
Cross Section E-E

This structural cross-section[2] is drawn along a line running North 50° East and extending form west of the Flathead River on the southwest across the valley of the Flathead River, the Clarke Range of the Rocky Mountains, the Rocky Mountain foothills, and into the plains of southern Alberta. The surface geology for the cross-section is taken from various sources. That west of the Flathead River is from Geological Survey of Canada Memoir No. 87, by J. D. MacKenzie. The eastern part of the Clarke Range and a part of the foothills is from the Beaver Mines Sheet,[3] mapped by C. O. Hage, and the eastern part of the foothills is from the Pincher Creek Sheet,[4] mapped by R. J. W. Douglas. The surface geology of the western part of the Clarke Range was taken partly from unpublished mapping by Mr. Jack Crabb, for the Crow's Nest Coal Company, supplemented by mapping by the author. In addition, the writer had the benefit of comparing notes regarding surface geology with the geologists of several oil companies. A limited amount of subsurface geological control was furnished by drilled wells. The drilling at Pincher Creek supplied the depth of the top of the Madison limestone in the foothills belt east of the Rockies, and Pacific Atlantic Flathead No. 1 furnished subsurface information to 10,500 foot depth in the western part of the Clarke Range.

The Clarke Range consists essentially of a broad open syncline of Precambrian Beltian strata lying as a thrust sheet above the Lewis thrust fault. This thick sheet of Precambrian rocks, lying above the Lewis thrust and bounded on the west by the Flathead fault, is herein referred to as the Clarke Range thrust sheet salient. It moved many miles northeastward along a seventy-five mile salient extending from Montana into southern British Columbia and Alberta. It overrode the position equivalent to the front ranges of the Rocky Mountains in Montana, as well as part of the foothills belt in both Alberta and Montana. It had its roots west of the Flathead Valley. In moving eastward, the Clarke Range thrust sheet cut across faulted foothills structures, where the earlier faults had smaller displacements than they have to the north and south, and where the fault slices in the overridden block had relatively low structural relief. As a result, the Clarke Range thrust sheet salient appears to have overridden Mesozoic strata along the major part of its course. A number of the faulted structures of the foothills and front ranges of the Rockies north and south of the salient expose Madison limestone as high individual ranges. However, these structures plunge precipitously as the thrust sheet is approached, and as a result the Precambrian rocks lie on Cretaceous strata. The relatively low structural relief of the overridden block along the length of the salient is evidenced by the fact that the Madison limestone reaches elevations up to 7,000 feet above sea level in the faulted ranges to the north and in the front ranges in Montana to the south, whereas it is 7,000 feet below sea level on top of the Pincher Creek structure on strike with these ranges and close in front of the salient.

The conclusion that the Clarke Range sheet salient largely overlies Mesozoic rocks is partly confirmed by the existence of a window in the Lewis thrust in Cate Creek, a Flathead tributary in the western part of the Clarke Range. At this place Upper Colorado shale overlain by basal Belly River is exposed in the deep canyon, below 1,500 feet of Precambrian belt strata. The Lewis fault plane at this place is nearly horizontal.

[1] Vice-President, Exploration, Pacific Petroleums Ltd., Calgary, Alberta.
[2] In addition to being shown on the large regional map, this cross-section is shown on the small geological map covering part of Montana, southeast British Columbia and southwest Alberta. This map was compiled by the writer from various sources.
[3] Geological Survey of Canada, Map No. 739A.
[4] Geological Survey of Canada, Paper 51-22.

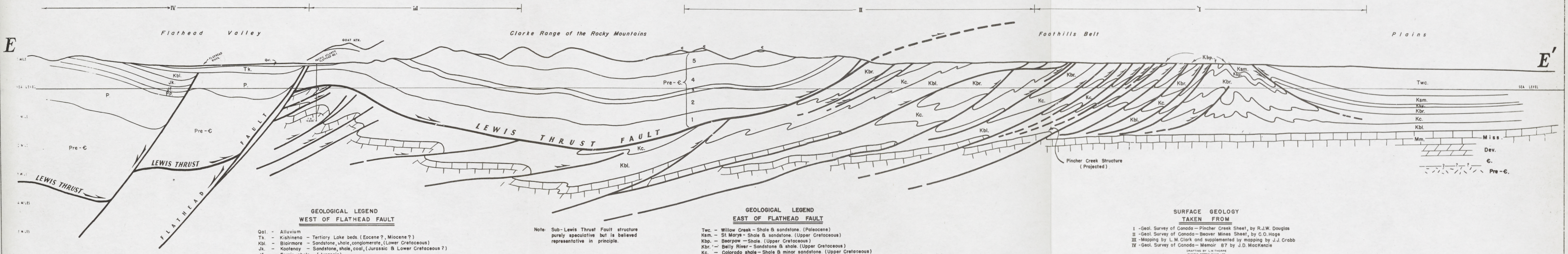

GENERALIZED GEOLOGICAL MAP
OF
CLARKE RANGE OF THE ROCKY MOUNTAINS AND VICINITY *
49°30'
PINCHER CREEK
E'
Lewis Thrust
Flathead Fault
Clarke Range of Rocky Mountains
Lewis Thrust
49°00'
INTERNATIONAL BOUNDARY
CANADA
U.S.A.
LEGEND
Tertiary
Paleocene Willow Creek fm. east of Rocky Mts.
Eocene? and Miocene? Kishinena formation West of Flathead Fault.
Mesozoic
Paleozoic
Pre€ Pre-Cambrian Belt Series
* Areal Geology compiled from various published and unpublished maps and author's work. Montana portion from Mont. Bur. of Mines, Geol. Mem. 4 by C.H. Clapp.
E ——— E' Line of cross section
KALISPELL
Pre-€
SCALE
0 10 20 Miles
48°00'
114°30'
114°00'
L. M. Clark
July 1954

CROSS SECTION E-E′
FROM
FLATHEAD VALLEY THROUGH CLARKE RANGE TO ALBERTA PLAINS

L. M. CLARK

VERTICAL & HORIZONTAL SCALE IN MILES
1 0 1 2 3 4 5

JULY 1954



GEOLOGICAL LEGEND
WEST OF FLATHEAD FAULT

Qal. - Alluvium
Tk. - Kishinena - Tertiary Lake beds. (Eocene ?, Miocene ?)
Kbl. - Blairmore - Sandstone, shale, conglomerate, (Lower Cretaceous)
Jk. - Kootenay - Sandstone, shale, coal, (Jurassic & Lower Cretaceous ?)
Jf. - Fernie-shale - (Jurassic)
Pp. - Permo-Pennsylvanian - Sandy dolomite & dolomitic ss. and possibly Triassic shale.
P. - Paleozoic { Mississippian - Mostly Limestone; Devonian - Dolomite & Limestone; Cambrian - Quartzitic Sandstone & Shale }
Pre-€ - Belt Series - Pre-Cambrian - Dolomite, Quartzite, Meta-argillite, etc.

Note: Sub-Lewis Thrust Fault structure purely speculative but is believed representative in principle.

GEOLOGICAL LEGEND
EAST OF FLATHEAD FAULT

Twc. - Willow Creek - Shale & sandstone. (Paleocene)
Ksm. - St. Marys - Shale & sandstone. (Upper Cretaceous)
Kbp. - Bearpaw - Shale. (Upper Cretaceous)
Kbr. - Belly River - Sandstone & shale. (Upper Cretaceous)
Kc. - Colorado shale - Shale & minor sandstone. (Upper Cretaceous)
Kbl. - Blairmore - Sandstone, shale & coal. (Lower Cretaceous) and Kootenay + Fernie (Jurassic)
M. - Madison limestone - Only the top of the Paleozoic limestone sequence is shown in the subsurface. Devonian limestone & dolomite present below Mississippian.
€. - Cambrian - Quartzitic sandstone and shale.
Pre-€ { 5 Kintla - Red and green argillite and quartzite.; 4 Siyeh & Sheppard - Limestone, dolomite, argillite & lava flow.; 3 Grinnell - Red ripple marked argillite.; 2 Appekuny - Quartzite & green argillite.; 1 Waterton & Altyn - Dolomite, limestone & argillite. } Belt or Lewis series.

Note: Going westward beneath the Lewis Thrust "Kbl" includes Triassic and Permo-Penn which are missing east of the Clarke Range.

SURFACE GEOLOGY
TAKEN FROM

I - Geol. Survey of Canada - Pincher Creek Sheet, by R.J.W. Douglas
II - Geol. Survey of Canada - Beaver Mines Sheet, by C.O. Hage
III - Mapping by L.M. Clark and supplemented by mapping by J.J. Crabb
IV - Geol. Survey of Canada - Memoir 87 by J.D. MacKenzie

DRAFTING BY L.W. THORPE
PACIFIC PETROLEUMS LTD.

Pacific Atlantic Flathead No. 1, shown on the cross-section, was drilled on an anticline in the Beltian strata near the truncated western edge of the Clarke Range sheet salient. This well was located and drilled with the objective of penetrating the Lewis thrust and testing the underlying younger rocks presumed to be present. At 4,500 feet it passed from the Precambrian rocks into highly disturbed Palaeozoic and early Mesozoic strata, and it is very difficult to draw any other conclusion than that this fault is the Lewis thrust.

The Flathead fault, that truncates the Clarke Range sheet salient on the west, is a great westward dipping fault of more than one hundred miles length. The west dip of this fault is clearly shown by its trace along the west face of the Clarke Range, on the east side of the Flathead Valley.

The geology of the Flathead Valley is largely obscured by alluvium and glacial debris. However, here and there Palaeozoic, Mesozoic, and even Tertiary beds, outcrop along the river and to the west. This area of younger sedimentary rocks must have been faulted either upward or downward along the west dipping Flathead fault, and geologists from the time of Bailey Willis to the present have offered various interpretations of the direction of dip of the fault and the relative displacement. The writer's interpretation comes back to that of Bailey Willis, which is that it is a west dipping normal fault. It is clear that the Flathead fault is subsequent to and that it cut the Lewis thrust fault. This is the only interpretation that fits the presently known geological facts. The Flathead fault diminishes in throw to the north and apparently dies out in the general latitude of North Kootenay Pass. At the Pass, the Clarke Range sheet dips northwestward beneath Palaeozoic rocks, the Cambrian, Devonian and Mississippian strata overlying the Precambrian with normal contacts and sequence. To the south in the vicinity of Marias Pass in Montana, the continuation of the Flathead fault cuts the Lewis thrust, bringing middle Beltian strata of the overlying thrust sheet against Cretaceous strata of the underlying block.

The Flathead Valley, for some distance on each side of the International Boundary, contains eastward tilted Tertiary lake beds which are reported to show at least one angular unconformity. These are highly fossiliferous, bituminous, and lignitic beds of weak consolidation and fresh water origin. They reach a thickness of perhaps 1,500 feet, and appear to have been deposited in the asymmetric basin created by the displacement along the Flathead fault. These Tertiary strata bear no resemblance to the Paleocene of the Alberta Plains, and from their general unaltered appearance suggest that they have never been overridden by a thrust sheet, such as the Clarke Range sheet. The conclusion is drawn that these lake beds were deposited in an elongate down-faulted block, the maximum throw being along the middle part of the Flathead fault. This would account for their origin and preservation.

MINERAL DEPOSITS IN THE SOUTHERN ROCKY MOUNTAINS OF CANADA[1]

M. S. HEDLEY[2]

INTRODUCTION

Placer gold was discovered on Wild Horse River in 1863, and on Bull River in the same year or shortly after. The only other stream in the Rocky Mountains known to contain placer gold is Maus Creek, a short distance south of Wild Horse River. The total production of placer gold is not known because records were not kept in the earliest days, and the most accurate statement that may be made is that more than one million and possibly several million dollars worth of gold was produced.

The earliest prospecting for lode was in the vicinity of the placer diggings, and a good deal of exploratory work was done prior to 1900. No source of the placers has been found, inasmuch as no vein containing important quantities of gold is known. Most of the deposits are of copper, lead, and zinc minerals, with associated small amounts of gold and silver.

Prospectors in search of lode were active in the years of the early railroad building, starting in 1883, and principally in the general area between Windermere and Golden. The metal chiefly sought was silver, in the early recognized absence of gold ore, and because of the common association of metals many deposits of lead and zinc were investigated, in the hope of discovering silver ore high enough in grade to be worked. In this second period of activity discoveries were made chiefly in the Purcell Mountains, but some were also made in the Rockies, and many prospectors must have worked east of the Rocky Mountain Trench.

The Monarch lode in Mount Stephen was discovered in 1884 when float was found on the location line of the railway. The Kicking Horse lode was discovered at a somewhat later date, and did not receive much attention until 1925. Development of the Monarch was rapid, and shipments of ore were made from it to Vancouver in 1888. A comparatively late discovery was that on Hawk Creek in 1929. In 1912 lead-zinc ore was discovered in Alberta at the head of Oldman River, and in 1951 silver-lead mineralization was discovered near Windermere.

G. M. Dawson's report of 1885 mentions "lead and copper ores, containing silver" between the Ottertail River and Field, copper about 5 miles north of Castle Mountain, copper on Copper Mountain on the south side of the Bow River, lead on the east side of Mount Ball, and copper on the Cross River.

Production has come from the Monarch and Kicking Horse mines, and in recent years from the Estella and Kootenay King. Shipments of a few tons of ore have been made from two or three prospects in past years.

It has been the practice to look upon mineralization in the Rocky Mountains as a rarity, and to consider it to be in a somewhat different category from mineralization in the Purcell Mountains. The important ore deposits at Field have been referred to as related genetically to the Ice River Complex, that being the nearest known body of igneous rock, in spite of the fact that the deposits are separated from it by 12½ miles. This attitude has cast doubts on the possibility of finding additional important ore deposits in the Rockies as a whole, whereas evidence of mineralization actually is widespread, and deposits are known even farther from any known igneous rock than Field is from the Ice River Complex. The structures in the western Rockies are not greatly different from those west of the Trench. There is no definite information on the age of mineralization, but deposits on the west side of the Trench are more likely post-

[1] Published by permission of the Chief of the Mineralogical Branch, British Columbia Department of Mines. Reference should be made to map, page 117.
[2] Senior Geologist, British Columbia Department of Mines.

Cretaceous than not. Whatever the structure of the Trench may be, it had an early beginning, probably long before the appearance east of the Trench of syenite dykes that are considered to be probably Tertiary in age (Rice, 1937, p. 24).

All other production is dwarfed by that of the giant Sullivan mine near the western edge of the Trench, a fact that tends to minimize the fact that the southwestern Rockies are reasonably well mineralized. Were it not for the Sullivan, the Monarch and Kicking Horse mines would be more widely recognized as major deposits.

In the western Rocky Mountains most of the quartz vein type of deposits have been found in the Precambrian rocks north and south of Wild Horse River, and so might express an affinity for those rocks, but such deposits have not been found south of Elko, or farther north near Canal Flats, where rocks of the same age are known to occur. There is a suggestion from their distribution that many of these deposits are related to faulting along the Trench margin, and to diagonal faults near Wild Horse River. Only a relatively few square miles of this region have been mapped in detail, and additional work may throw light on the structural situation of many occurrences of mineralization.

Many of the mineral deposits in the Precambrian rocks are related to bodies of diorite and syenite. It has not been established whether this means that the deposits are related genetically to the igneous rock, and if so how direct the relationship may be. In some instances it appears that the relationship is structural, and that fracturing has been localized in or marginal to a sill or dyke.

Any discussion of mineralization in the Rocky Mountains must include the Sullivan and Silver Giant mines; the Sullivan because it is the most important single deposit in Western Canada, and the Silver Giant because it is in lower Palaeozoic rocks and is related to structures typical of the Western Rockies.

PRODUCING MINES

SULLIVAN MINE

The great Sullivan mine of the Consolidated Mining and Smelting Company of Canada, Limited, is 1½ miles northwest of Kimberley, on the west side of the Rocky Mountain Trench. The lead-zinc ore is concentrated and shipped to the company's smelter at Trail. Ore is mined at the rate of about 10,000 tons a day, and in 1952 a total of 2,699,533 tons was mined, with a gross metal content in concentrates of 2,846,304 ounces of silver, 215,000,283 pounds of lead, and 258,139,395 pounds of zinc.

The ore is a sulphide replacement of a stratigraphic zone 200 to 300 feet thick, in the lower part of the Precambrian Aldridge formation. The principal sulphides are galena, sphalerite, pyrrhotite, and pyrite. Small amounts of chalcopyrite and arsenopyrite are present and locally boulangerite. Magnetite is fairly common and cassiterite is present in small but commercial amounts. The footwall rock, particularly above the 3900 level, is strongly tourmalinized to a product that resembles dark coloured chert. Chloritization of the hangingwall is extensive; albitization of the hangingwall is more restricted but locally extends higher than the chloritization. Replacement was of uniformly bedded, and for the most part finely laminated, argillite and silty argillite. The relatively great permeability of these rocks may be ascribed to their laminated character, and to the fact that the section shows great uniformity throughout long distances; individual beds have been traced for thousands of feet in spite of the fact that they are at most 20 feet thick.

Bodies of Purcell intrusives, occurring commonly as sills or as sheets at small angles to the bedding, are common in the area. They are generally referred to as diorite, but their composition has a considerable range. They produced some metamorphism of the intruded rocks.

The ore zone is in the hangingwall of the east-west striking Kimberley fault, one of the major breaks in the general region. Three smaller northerly trending faults in and near the mine area apparently have an overlapping age relationship to the Kimberley fault.

In the mine area the regional dip is to the east and north, on the eastern flank of a broad anticline. The regional dip is modified by gentle warping and by minor sharp folds. Within the actual ore zone minor complex folding is common, and there are indications that folding and mineralization were to some degree contemporaneous or overlapping.

The origin of the ore zone is related to a major fault and minor faults that indicate repeated movement. These provided access for solutions from an unknown and possibly distant source. The extraordinary stratigraphic uniformity of the ore zone appears to have contributed to the formation of an exceptionally large and continuous orebody, and the fine laminations of the replaced beds seem to have been more important than their exact composition. Swanson and Gunning (1945) point out that there is evidence indicating either two stages of mineralization, or one long and variable stage. They find insufficient evidence to determine whether the mineralization was related in time and origin to the Purcell intrusives, or to the much later intrusives of Cretaceous or early Tertiary age.

SILVER GIANT MINE

The Silver Giant mine is on the west side of Jubilee Mountain about 7 miles by road from Spillimacheen. It is in Jubilee magnesian limestone just east of a major westerly dipping fault, on which Horsethief Creek strata, of Precambrian age, are thrust over the lower Palaeozoic. The mine is west of the Rocky Mountain Trench proper, between the Trench and the subsidiary trench of the Spillimacheen valley.

Lead-zinc ore is mined at the rate of about 500 tons per day. The grade of ore mined has been less than 1 ounce of silver per ton, about 4 per cent lead, and about 1 per cent zinc. Ore has been mined through a vertical range of about 700 feet, from a surface glory hole to No. 7 level, which is reached by an internal shaft from No. 6 adit level.

The ore zone is in an overturned nose of Jubilee limestone, which plunges 45 degrees in the direction south 75 degrees west. Black slates are wrapped around the nose and there is some faulting and brecciation. Paper slates are seen in the crosscut for 900 feet southwest of the nose, and are different from limy slates on the surface to the northeast. They may be Horsethief Creek strata, but the main regional thrust is believed to lie farther to the southwest, and only subsidiary faults occur in the mine workings.

Replacement of the limestone by barite and more or less fine-grained silica has occurred in the nose, and, to a lesser extent, along both limbs of the fold. The ore is confined to the barite zone and consists of fine-grained galena, and scattered pyrite and sphalerite. There are local small amounts of chalcopyrite, bornite, and a grey copper-arsenic mineral. Some of the ore is highly siliceous and is marked by clots and wisps of dark grey silica which represent silicified slate fragments at and near the limestone-slate contact.

The steeply plunging ore-bearing structure is strongly at variance with a low southeasterly plunge, evident from about 1,500 feet to 1 mile northwest of the mine. There is obviously a marked change of direction of plunge. The ore structure appears to be anomalous, but outcrops are very scanty and detailed areal mapping has not been done. A line of showings, containing barite and small amounts of sulphide, extends eastward on the line of the ore structure

to the crest of Jubilee Mountain. Presumably these showings represent the roots of the eroded ore structure, which plunged at a somewhat steeper angle than the line of showings.

Other showings of lead-zinc mineralization occur on Jubilee Mountain and on the eastern side of it, but have not been sufficiently developed to indicate their size. There is no exploration activity at the present time.

THE MONARCH AND KICKING HORSE MINES

These are described in some detail on other pages of this Guidebook, by C. S. Ney. It is sufficient to emphasize here that they constitute the largest orebodies at present known in the Rocky Mountains. Continuity of the orebodies across the 3,800-foot gap of the Kicking Horse River cannot, of course, be proved, but it seems probable that the dolomitic alteration zone in which they occur was continuous between the two mines, and that the several orebodies are parts of a single, although not necessarily continuous, ore zone. If so, the original ore zone was of major proportions, being at least 7,000 feet long.

OTHER MINERALIZED LOCALITIES

OTTERTAIL RIVER

Several old prospects on the Ottertail and its tributaries received attention at the time of completion of the Canadian Pacific Railway, and ores from this source as well as the Monarch deposit were considered in early attempts at smelting. At the head of Silver Slope Creek a bed, 6 feet thick, of Chancellor limestone, is cut by mineralized calcite stringers, and is impregnated with irregular lenses of galena, sphalerite, and pyrite, and small amounts of chalcopyrite and probably argentite. At the head of Haskins Creek a prospect shows chalcopyrite and pyrite associated with quartz veins in slates. On Frenchman Creek quartz-calcite veinlets in slates contain galena, tetrahedrite, azurite, malachite, pyrite, and some arsenopyrite. One-half mile from the railway, chalcopyrite, galena, sphalerite, pyrite, tetrahedrite, and in one place fluorite, are associated with quartz and calcite stringers in slaty rocks of the sheared Chancellor formation.

ICE RIVER

On Shining Beauty Creek, a tributary of Ice River, a quartz-calcite vein 2 feet wide contains pyrite, galena, and a small amount of chalcopyrite. Pockets of arsenopyrite and quartz occur in limestone, locally with associated sphalerite and bornite. In Zinc Valley a band of siliceous limestone 2 to 3 feet thick, between argillites, contains a lenticular mass of sulphides consisting of sphalerite, bounded successively by arsenopyrite and pyrite.

MOOSE CREEK

On Zinc Mountain, at the head of Moose Creek and close to the eastern margin of the Ice River Complex, lenses of sphalerite, pyrrohotite, galena, and chalcopyrite occur in limestone and calcareous shales. Knopite and magnetite were reported from the vicinity of Moose Creek in 1925 (Geol. Surv., Canada, Sum. Rept. 1925, p. 230), and in 1952 and 1953 the occurrence of minerals containing titanium, niobium, thorium, and uranium was reported.

HAWK CREEK

A lead-zinc deposit was discovered on the north side of Hawk Creek in 1929, about 2 miles east of the Banff-Windermere Highway. Permission to do assessment work was refused by the National Parks Board in 1932, but the showings were diamond drilled in 1942 as a war-time measure to investigate possible reserves of lead and zinc. No further work has been done on the property.

The rocks in the area consist of a series of interbedded limestones and argillites, of probable Upper Cambrian or Ordovician age. At the showing the beds dip gently or are horizontal, and are cut by a shear zone that dips 45 to 70 degrees to the southwest. The deposit is localized at the intersection of the shear zone and a limestone bed. The ore consists largely of sphalerite, replacing limestone, and is banded parallel to the shear, but the controlling factor in deposition appears to have been lithological. At the surface the ore zone is an irregular shaped body about 55 feet wide and as much as 18 feet thick. Drilling has indicated a pencil-like body of variable outline, with a low rake to the northwest. An interpretation by Henderson (Minister of Mines, British Columbia, Ann. Rept., 1953) of the diamond drilling data indicates the presence of 29,500 tons of ore, averaging 12.5 per cent zinc. The lead content is reported to be low and the silver content negligible.

CROSS RIVER

On the Cross River two main diorite sills and a few small sills and dykes occur. The main sills contain many small transverse quartz, calcite, and quartz-calcite veins; some of the last named contain small amounts of pyrite and chalcopyrite, and, rarely, tetrahedrite, galena, and sphalerite.

OLDMAN RIVER

The Bearspaw lead-zinc deposit at the head of the Oldman River was discovered in 1912, by hunters, but was not staked until 1950. It is on the east side of the Elk Range, at an elevation of about 7,000 feet, and is accessible from the Kananaskis road by a rough truck road completed in 1953. It is at present under option to Western Canada Collieries, who have done some surface work.

The deposit is a replacement by galena and sphalerite of dolomite, near the top of the Devonian, about 200 feet above a sole fault on which Palaeozoic strata are thrust over Cretaceous sandstones and shales along a 40-mile front. The mineralization is, according to early reports, about 4 to 4½ feet wide, and is in a strongly fractured zone dipping 40 degrees westward. Lead and zinc are present in approximately equal amounts, but initial sampling did not indicate a particularly high grade. One other small occurrence of similar material has been found several miles distant.

SWANSEA MOUNTAIN

On Swansea Mountain, east of Athalmer, a deposit of copper has been known for many years. A breccia zone in upper Jubilee dolomite contains narrow and discontinuous stringers in the calcite and hematite cement. The stringers contain bornite and chalcopyrite, and secondary malachite and azurite.

MADIAS CREEK

On the western front of the Rocky Mountains, a mile north of this creek, a discovery of lead-zinc mineralization in dolomite was made in 1951. An apparently isolated pod as much

as 15 feet wide, and exposed for 35 feet on the slope, consists of highly oxidized, brecciated, dolomite partly replaced by galena and a little sphalerite.

WASA CREEK

At the head of Wasa Creek, 9 miles northeast of Wasa, a quartz vein 2 feet thick is reported to contain tetrahedrite and copper carbonates.

LEWIS CREEK

Old reports mention a 4-inch quartz vein containing copper mineralization, and a quartz vein 6 to 8 feet thick containing galena stringers.

ESTELLA MINE

The Estella mine is at the head of Tracy Creek in the western range of the Rockies, east of Wasa and 11 miles north of Fort Steele. The mine is accessible from the mill-site at Wasa by a good road 16½ miles long.

The mine is a very old one that was investigated at various times in the past. The present owners, Estella Mines Limited, acquired the property in 1950, and built a 200-ton mill that was in operation late in 1951. The readily available ore was exhausted early in 1953 and subsequent development to the end of 1953 was not encouraging, and in consequence all operations ceased.

The rocks are in the transition zone between the Aldridge and Fort Steele formations, intruded by a body of diorite which is sill-like in over-all form. A small body of syenite occurs at one adit portal. The lode dips to the southwest and is a zone of fracturing and light shearing semi-bedded in the sediments, and penetrating diorite in the mine workings. The ore is a replacement by sphalerite, galena, and pyrite, accompanied by more or less silica. Vein quartz is not abundant and as a rule is not mineralized. The zinc to lead ratio averages about 2 1/3:1, and about 1 ounce of silver per ton is present. A small amount of cobalt is associated with the sphalerite. Ore occurs in grey argillite, in quartzite, and in diorite; the reasons for localization are not obvious, but there may be a relation to the diorite contact.

About 70,000 tons of ore have been mined, with a grade of 14 per cent combined lead and zinc.

HERBERT CREEK

On this small creek 8 to 9 miles north of Fort Steele three showings have long been known. One is a breccia zone in quartzite, mineralized with chalcopyrite and pyrite. Another consists of quartz-calcite lenses in the upper part of a large diorite sill, and containing galena, pyrite, and chalcopyrite. The third comprises several quartz veins as much as 24 inches wide, in limestone, and containing iron sulphides.

KOOTENAY KING MINE

The Kootenay King mine is on the north side of Wild Horse River, 10 miles northeasterly from Fort Steele. The lowest adit is at an elevation of 7,100 feet. This is another old property which was explored at intervals over the years. It was equipped with a mill in 1951 and started to produce the next year. Production was continuous from March to December of 1952, when low prices forced curtailment. Some broken ore was milled during a short period in 1953, and all activity then ceased.

The ore is a replacement of dolomitic argillite, intercalated with quartzite bands in the transition zone between the Aldridge and Fort Steele formations. The ore zone is localized within a minor dragfold in the steeply dipping strata. The argillite is a soft, dense, grey rock with a total width across two bands of about 60 feet. It is crumbled in the dragfold and is cleaved axially to the fold. The dragfold plunges at a low angle to the north. The ore is a replacement by fine-grained sphalerite, galena, and pyrite.

About 16,000 tons of ore were milled, containing between 6 and 7 per cent each of lead and zinc, and about 2 ounces of silver per ton.

WILD HORSE RIVER

A number of old properties are known in the basin of Wild Horse River and its tributary, Boulder Creek. Rather more work was done on these showings than the indications would normally warrant, because a source of the local placer deposits was sought diligently in the early days. All of the showings consist of quartz veins and quartzose zones, cutting Precambrian and Cambrian sediments, and in many instances associated with syenite dykes. The dykes are locally shattered and partly altered, and quartz occurs in or alongside them as vein stringers and replacement masses, a few inches to a few feet wide. The minerals present are galena, chalcopyrite, pyrite, and a little sphalerite. Quartz stringers containing visible gold have been noted in the Big Chief group.

MAUS CREEK

The Victor group at the head of Maus Creek, east of Fort Steele, is in Creston argillaceous quartzites. Three adits have been driven on a quartz-filled fissure about 2 feet wide, which is irregularly mineralized with galena, sphalerite, and pyrite. A 50-ton concentrator was build thirty years ago, but only a few tons of concentrate were shipped. Of two showings on Maus Mountain south of Maus Creek, one consists of a quartz vein in the Aldridge formation and contains pyrite and chalcopyrite; the other is a quartz vein, 4 feet thick, in a diorite sill, and contains small amounts of chalcopyrite and pyrite.

SUNKEN (LOST) CREEK

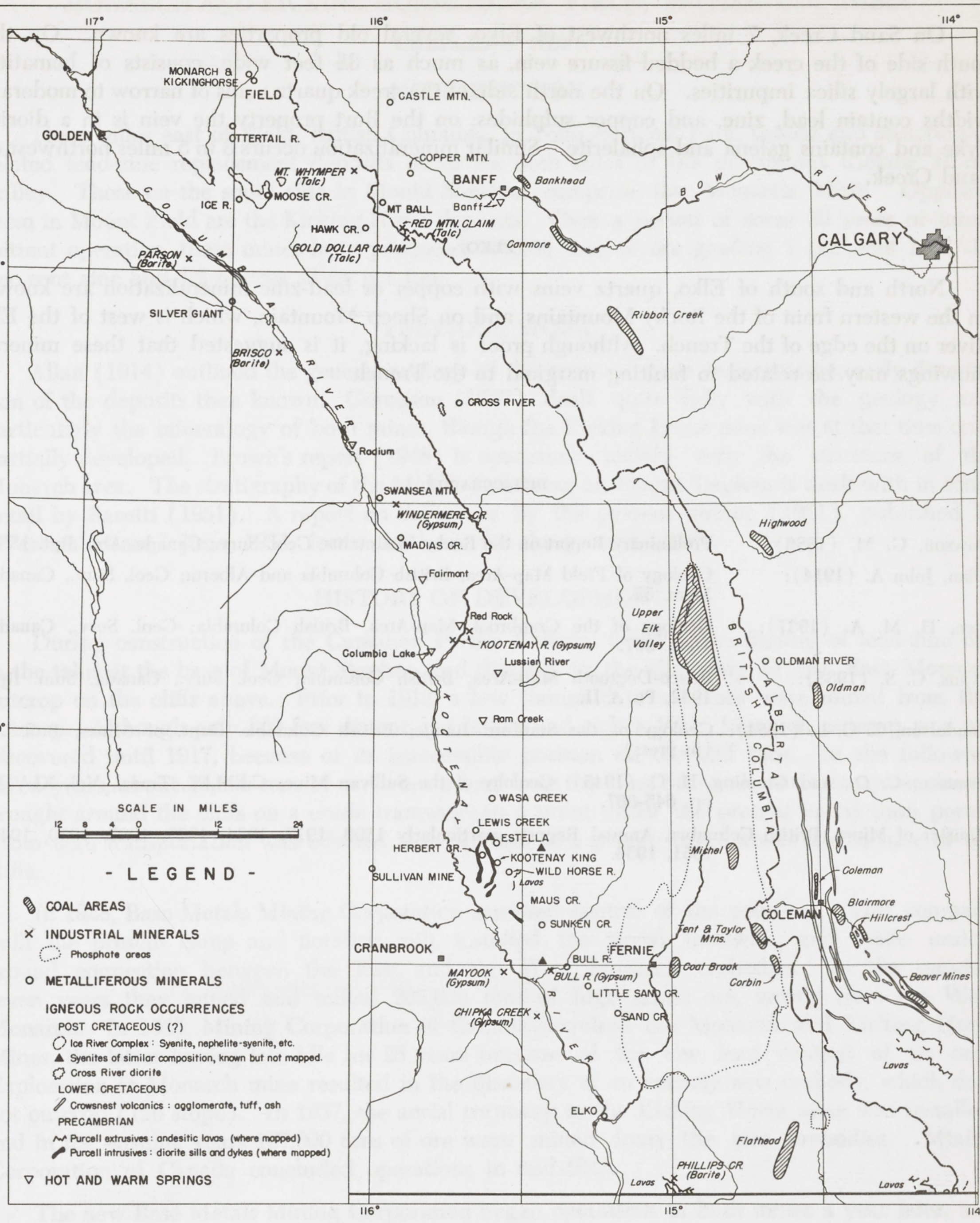
At the head of this creek, 7 miles southeast of Fort Steele, a quartz vein or quartz stringer zone has had two adits and a shaft driven in it. Stringers and pockets of "copper" are reported and the presence of tetrahedrite is mentioned.

BULL RIVER

South of Bull River and about 5 miles from its mouth, hematite is reported to fill fractures at right angles to the formation, and to spread out into bodies replacing "porous rock." The best of many showings is said to be 10 feet wide. At 6 to 7 miles from the mouth of Bull River, and on both sides of the river, mineralization is associated with a prominent diorite dyke. Minerals occurring in cleaved and fractured zones along the dyke margins include sulphides of copper, lead and zinc.

LITTLE SAND CREEK

At the head of this creek, between Elko and Bull River, a "strong quartz filled fissure" is reported to contain siderite, galena, sphalerite, pyrite, and some chalcopyrite. At a lower elevation a quartz-filled fissure in slates is reported to contain mineral, but only at cross fractures.



MINERAL OCCURRENCES, IGNEOUS ROCKS AND HOT SPRINGS
OF THE
SOUTHERN CANADIAN ROCKY MOUNTAINS

TO ACCOMPANY PAPERS BY

J. A. Allan, H. C. Gunning, M. S. Hedley, J. M. McCammon, Miss B. J. Pickering, R. T. D. Wickenden, C. S. Ney

MAP 2

SAND CREEK

On Sand Creek, 7 miles northwest of Elko, several old properties are known. On the south side of the creek a bedded fissure vein, as much as 3½ feet wide, consists of hematite, with largely silica impurities. On the north side of the creek quartz veins of narrow to moderate widths contain lead, zinc, and copper sulphides; on the Burt property the vein is in a diorite dyke and contains galena and sphalerite. Similar mineralization occurs 3 to 5 miles northwest of Sand Creek.

ELKO

North and south of Elko, quartz veins with copper or lead-zinc mineralization are known on the western front of the Rocky Mountains, and on Sheep Mountain, which is west of the Elk River on the edge of the Trench. Although proof is lacking, it is suggested that these mineral showings may be related to faulting marginal to the Trench.

BIBLIOGRAPHY

Dawson, G. M. (1886): Preliminary Report on the Rocky Mountains; Geol. Surv., Canada, Ann. Rpt. 1885.

Allan, John A. (1914): Geology of Field Map-Area, British Columbia and Alberta; Geol. Surv., Canada, Mem. 55.

Rice, H. M. A. (1937): Geology of the Cranbrook Map-Area, British Columbia; Geol. Surv., Canada, Mem. 207.

Evans, C. S. (1933): Brisco-Dogtooth Map-Area, British Columbia; Geol. Surv., Canada, Sum. Rpt. 1932, Pt. A II.

Henderson, G. G. L. (1954): Geology of the Stanford Range; British Columbia Dept. of Mines, Bull. 35 (in press).

Swanson, C. O., and Gunning, H. C. (1945): Geology of the Sullivan Mine; C.I.M.M., Trans., Vol. XLVIII, pp. 645-667.

Minister of Mines, British Columbia, Annual Reports, particularly 1898, 1917, 1924, 1925, 1927, 1930, 1949, 1951, 1953.

MONARCH AND KICKING HORSE MINES, FIELD, BRITISH COLUMBIA

CHARLES S. NEY[1]

INTRODUCTION

Three miles east of Field, British Columbia, in Yoho National Park, similar and structurally related lead-zinc replacement deposits occur on both sides of the precipitous Kicking Horse Valley. Those on the south side in Mount Stephen comprise the Monarch Mine. Opposite them in Mount Field are the Kicking Horse deposits. Over a period of some 60 years of intermittent operation, these mines have produced 850,000 tons of ore grading 7 per cent lead, 10 per cent zinc and 1.2 ounces silver per ton.

PREVIOUS WORK

Allan (1914) outlined the general geology of the area and gave an interesting early description of the deposits then known. Goranson (1937) dealt quite fully with the geology and particularly the mineralogy of both mines, though the Kicking Horse mine was at that time only partially developed. Brown's report (1948) is concerned mainly with the structure of the Monarch area. The stratigraphy of the Middle Cambrian on Mount Stephen is dealt with in some detail by Rasetti (1951). A report on the mines by the present author (1951), published in "Western Miner," June, 1951, forms the basis for the present article.

HISTORY OF DEVELOPMENT

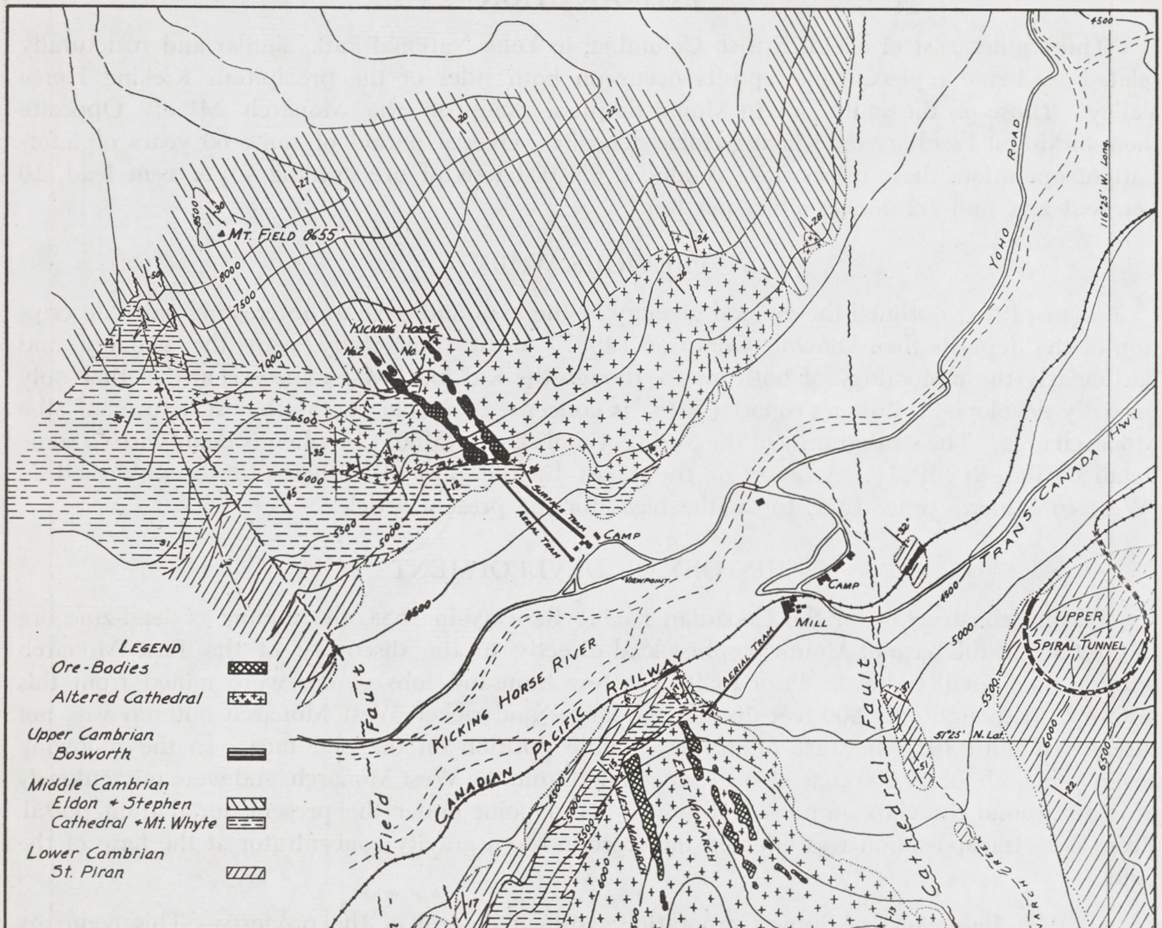
During construction of the Canadian Pacific Railway in 1884, the finding of lead-zinc ore in the talus at the base of Mount Stephen lead directly to the discovery of the East Monarch outcrop on the cliffs above. Prior to 1912, a few thousand tons of ore were mined from this outcrop. Although only 800 feet distant, the larger and richer West Monarch outcrop was not discovered until 1917, because of its inaccessible position on the cliff face. In the following seven years, about 10,000 tons of ore were mined from the West Monarch, and were miraculously brought around the cliffs on a crude tramway[2] to a point under the present aerial tram portal. From here transportation was effected underground to a gravity concentrator at the base of the cliffs.

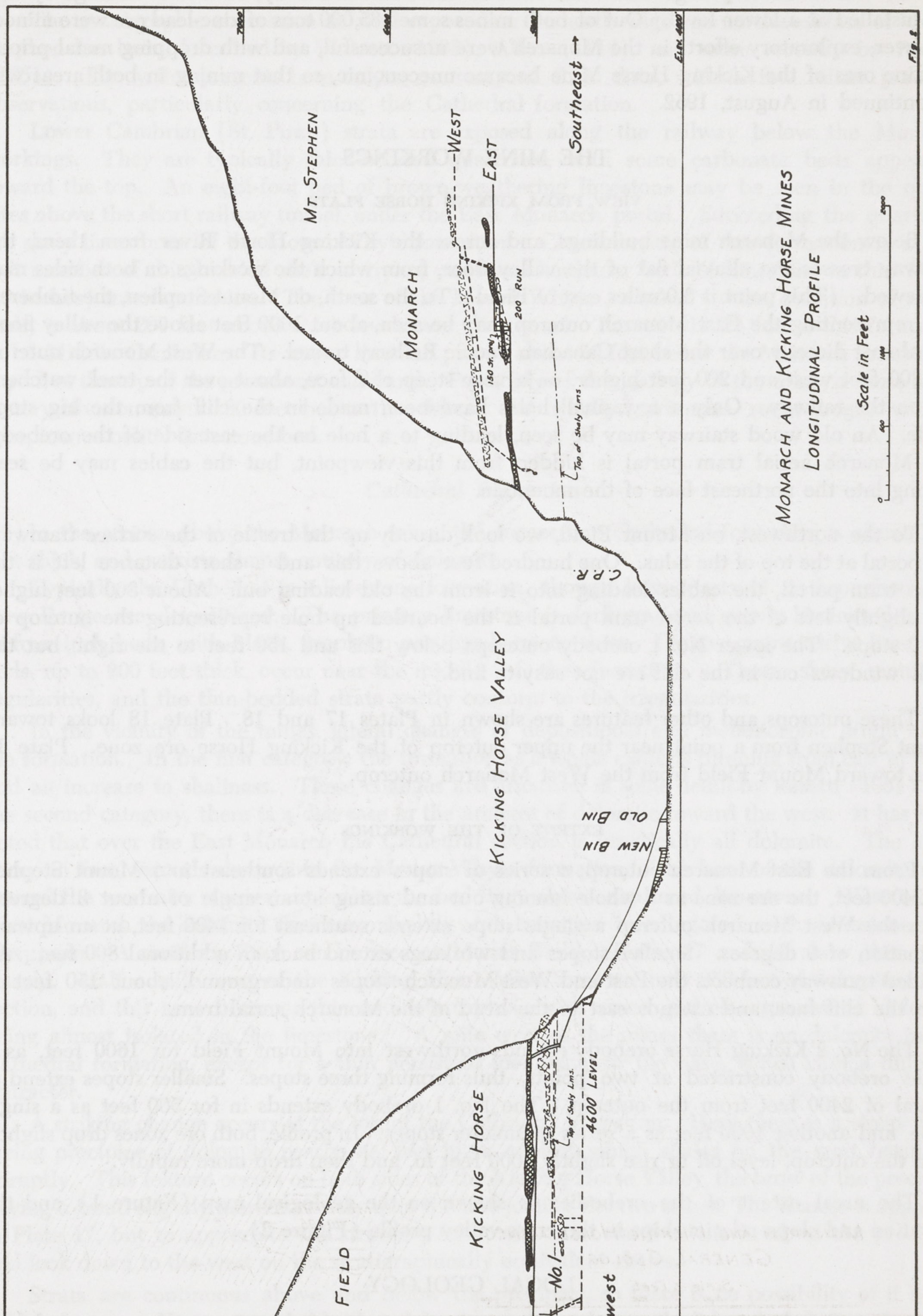
In 1928, Base Metals Mining Corporation assumed control of the property. This company built the present camp and flotation mill, installed the aerial tramway, and made underground connection between the East and the West Monarch orebodies. In the ensuing seven years they mined and milled 265,000 tons of high grade ore, mostly from the West Monarch. In 1935, Mining Corporation of Canada acquired the Monarch and Kicking Horse Mines, the latter having lain idle for 25 years because of the low lead content of its ores. Exploration in Monarch mine resulted in the discovery of an entirely new orebody, which does not outcrop (150 stope). In 1937, the aerial tramway to the Kicking Horse mine was installed, and in the ensuing years 167,000 tons of ore were mined from the two orebodies. Mining Corporation of Canada concluded operations in mid-1946.

The new Base Metals Mining Corporation began operations in both mines a year later, and was successful in finding a rich lead orebody (200 C), in the East Monarch area, along a zone largely unexplored by previous operators. Much good zinc ore was developed in the Kicking Horse mine by following the trends of the original orebodies. The lower of the two orebodies

[1] Geologist, Northwestern Explorations Ltd. Acknowledgment is made to Base Metals Mining Corporation for permission to publish this paper, and to the editors of Western Miner for permission to use information and illustrative material originally published in Western Miner.

[2] From a viewpoint on the Trans-Canada highway 0.7 miles east of the mine buildings, one of the steel brackets which supported this tramway may be seen in profile, projecting from the cliff forming the base of Mount Stephen.


Legend
Ore-Bodies
Altered Cathedral
Upper Cambrian
Bosworth
Middle Cambrian
Eldon + Stephen
Cathedral + Mt. Whyte
Lower Cambrian
St. Piran
Mt. Field 8655'
Kicking Horse
No. 2
No. 1
Surface Tram
Aerial Tram
Camp
Viewpoint
Mill
Kicking Horse River
Canadian Pacific Railway
Field – Stephen Fault
Cathedral – Stephen Fault
Yoho Road
Trans-Canada Hwy
Upper Spiral Tunnel
Monarch Creek
West Monarch
East Monarch
Glacier
Mt. Stephen 10,495'
51°25' N. Lat.
116°25' W. Long.
Monarch and Kicking Horse Mines
General Geology
Scale in Feet
0
1000
2000
3000
4000
5000
Fig. 1


Mt. Field
Kicking Horse
Kicking Horse Valley
Mt. Stephen
Monarch
West
East
Southeast
Northwest
No. 2
No. 1
4600 Level
New Bin
Old Bin
C.P.R.
200 Run
Monarch and Kicking Horse Mines
Longitudinal Profile
Scale in Feet
Fig. 8

(No. 1) was found to plunge below the level of the aerial tramway, so a new haulage system was installed at a lower level. Out of both mines some 185,000 tons of zinc-lead ore were mined. However, exploratory efforts in the Monarch were unsuccessful, and with dropping metal prices, the zinc ores of the Kicking Horse Mine became uneconomic, so that mining in both areas was discontinued in August, 1952.

THE MINE WORKINGS

VIEW FROM KICKING HORSE FLATS

Below the Monarch mine buildings, and across the Kicking Horse River from them, the highway crosses the alluvial flat of the valley floor, from which the workings on both sides may be viewed. (This point is 3.0 miles east of Field). To the south, on Mount Stephen, the timbered hole representing the East Monarch outcrop may be seen, about 1000 feet above the valley floor, and almost directly over the short Canadian Pacific Railway tunnel. The West Monarch outcrop lies 800 feet west and 200 feet higher, on a very steep cliff face, about over the track watcher's hut on the railway. Only a few small holes have been made in the cliff from the big stope inside. An old wood stairway may be seen, leading to a hole on the east side of the orebody. The Monarch aerial tram portal is hidden from this viewpoint, but the cables may be seen leading into the northeast face of the mountain.

To the northwest, on Mount Field, we look directly up the trestle of the surface tramway, to a portal at the top of the talus. One hundred feet above this and a short distance left is the aerial tram portal, the cables leading into it from the old loading bin. About 300 feet higher and slightly left of the aerial tram portal is the boarded up hole representing the outcrop of No. 2 stope. The lower No. 1 orebody outcrops below this and 150 feet to the right, but the small 'windows' cut in the cliff are not easy to find.

These outcrops and other features are shown in Plates 17 and 18. Plate 18 looks toward Mount Stephen from a point near the upper outcrop of the Kicking Horse ore zone. Plate 17 looks toward Mount Field from the West Monarch outcrop.

EXTENT OF THE WORKINGS

From the East Monarch outcrop, a series of stopes extends southeast into Mount Stephen for 2400 feet, the ore zone as a whole fanning out and rising at an angle of about 8 degrees. From the West Monarch outcrop a single stope extends southeast for 1400 feet, at an upward inclination of 9 degrees. Smaller stopes and workings extend back an additional 800 feet. An inclined tramway connects the East and West Monarch stopes underground, about 150 feet in from the cliff face, and extends east to the head of the Monarch aerial tram.

The No. 2 Kicking Horse orebody extends northwest into Mount Field for 1600 feet, as a single orebody constricted at two points, thus forming three stopes. Smaller stopes extend to a total of 2400 feet from the outcrop. The No. 1 orebody extends in for 500 feet as a single stope, and another 1000 feet as a series of smaller stopes. In profile, both ore zones drop slightly from the outcrop, level off or rise slightly 1000 feet in, and then drop more rapidly.

The areal extent of the orebodies is shown on the geological map (Figure 1), and the elevation and slope relationships in the cross-valley profile (Figure 2).

LOCAL GEOLOGY

All of the sedimentary rocks in the immediate vicinity of the Monarch and Kicking Horse mines are of Cambrian age. No igneous rocks occur in or around the mines. The nearest known representatives of the Ice River Complex lie about 13 miles to the south.

STRATIGRAPHY

The stratigraphic succession so well exposed on the north ridge and northwest face of Mount Stephen has been described by Walcott (1908), Allan (1914), and more recently by Rasetti (1951). The writer presents here only a summary of their data, with a few minor personal observations, particularly concerning the Cathedral formation.

Lower Cambrian (St. Piran) strata are exposed along the railway below the Monarch workings. They are typically thick-bedded quartzites, with some carbonate beds appearing toward the top. An eight-foot bed of brown-weathering limestone may be seen in the quartzites above the short railway tunnel, under the East Monarch portal. Succeeding the quartzites are shaly limestones, of the Mount Whyte formation. Characteristic of this formation is a 170-foot member of thin-bedded shale, carrying pods and lenticular beds of limestone in thin (0.2—2.0 inches) interlamination. The base of the Mount Whyte , marked by the cessation of sandy beds, is about 200 feet above track level, over the tunnel. Rasetti (1951) found this formation to be Middle Cambrian. Its upper limit he placed about 50 feet below the Monarch aerial tram portal, at the top of the prominent cliff band. For study of the geology of the mine, a more satisfactory division exists 100 feet below this, where the wholly carbonate rocks begin with a conspicuous oolitic limestone bed.

Cathedral Formation

In the section above the Monarch mine, the succeeding Cathedral formation is about 1900 feet thick, and consists almost entirely of dolomite.

Typically the Cathedral is a limestone formation, though large parts of it throughout the Bow Range are dolomitized. The primary limestone is dark gray and evenly laminated in one to four inch beds, with black, graphitic partings between them. Lighter gray massive limestone beds, up to 200 feet thick, occur near the middle of the formation. These show many irregularities, and the thin-bedded strata partly conform to the irregularities.

In the vicinity of the mines, lateral changes of depositional and metamorphic origin affect the formation. In the first category, the formation as a whole exhibits thinning from east to west, and an increase in shaliness. These changes are discussed in some detail by Rasetti (1951). In the second category, there is a decrease in the amount of dolomite toward the west. It has been noted that over the East Monarch the Cathedral section is practically all dolomite. The alteration, in fact, extends down into the Mount Whyte formation. The base of the dolomite rises toward the west at a steeper angle than the bedding, above unaltered limestone. West of the West Monarch the dolomite rises more rapidly and becomes interfingered with limestone and disappears. A similar pattern can be seen on Mount Field. Plates 17 and 18 show this quite clearly. Half a mile west of the Kicking Horse Mine there are only 350 feet of dolomite in the section, and this zone becomes thin and interrupted, with some globular masses of dolomite being almost isolated in the limestone.[1] A mile west of the mines there is no dolomite in the Cathedral formation, except for a thin persistent member near the base, which is of a different character.

A striking change occurs at the top of the Cathedral formation. Here there is a steep west-facing precipice of dolomite nearly 400 feet high, against which shales on the west terminate abruptly. This feature occurs on both sides of the Kicking Horse Valley, the brow of the precipice having a trend slightly more northerly than the line joining the two mines. The change is apparent in Plate 17, but to appreciate the structure fully, one must stand at the brink of the precipice and look down to the west on the stratigraphically equivalent shales.

Strata are continuous above and below the precipice, so there is no possibility of it being a fault feature. Nor is it probable that dolomite could replace a thick band of shales. It seems

[1] Rasetti (1951, p. 45) found boulder-like masses of dolomite in the Cathedral formation, west of the Monarch, which he considered to be of actual detrital origin, having fallen from the early-formed dolomite cliffs.

to be an original feature of deposition, originally built between limestone and shale, the limestones having been altered to dolomite. The structure resembles that of a reef. To the writer's knowledge, however, no organic remains have been found in this part of the Cathedral formation.

The abrupt appearance of shales marks the base of the Stephen formation, for which Rasetti (1951) gave a measured thickness of 376 feet. The upper 200 feet are dominantly limestone. The contact with the overlying Eldon is arbitrarily placed by Rasetti, a little higher than lithology would suggest.

The Eldon forms the massive cliffs in the upper 3000 feet of Mount Stephen. It consists mostly of well-bedded dolomite, with a shaly member near the middle of the formation. A few thick, irregular bands of thin-bedded, black limestone occur within the dolomite. One may be seen clearly in the view of Mount Field (Plate 17), below the hump on the east ridge.

The topmost 300 feet of Mount Stephen consist of thin-bedded dolomitic siltstone, conspicuously more resistant to weathering than the dolomites below. This is considered to be the Bosworth formation, of late Cambrian age.

STRUCTURAL GEOLOGY

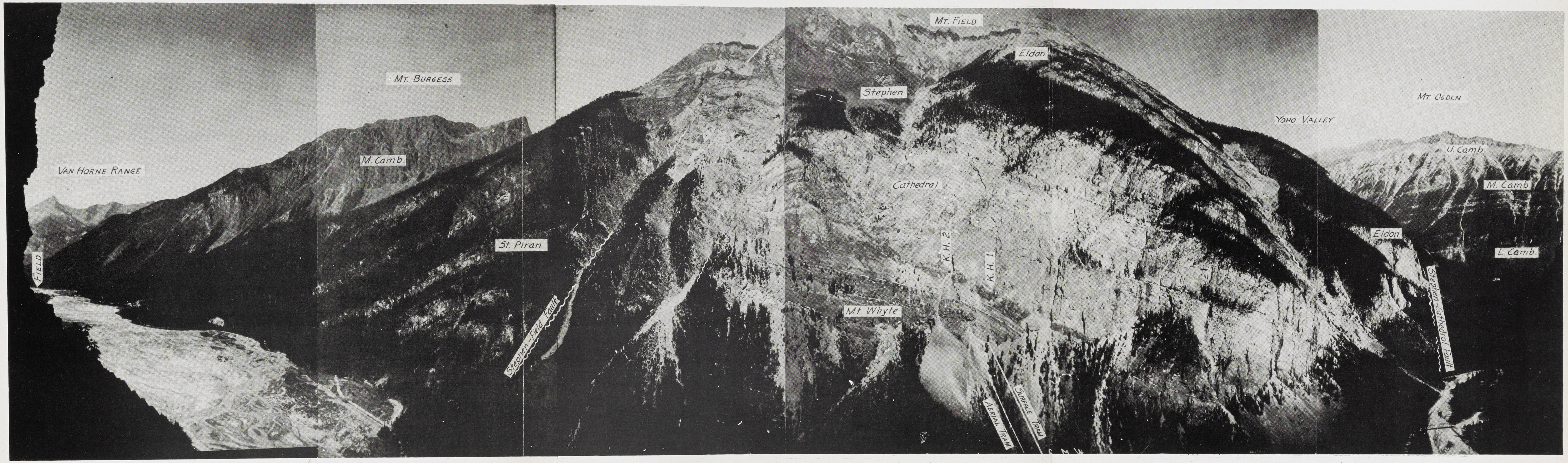
Folding

The mines are in the northeast flank of a gently domed, northwest trending anticline. The crest of the anticline is accentuated by a minor superimposed anticline, and crossed by the Stephen-Field fault, about a mile west of the mines. Figure 1 shows the pattern of dips in the mine area. In the Monarch mine they are quite regular, except for minor folds, at 10 to 15 degrees northeast. In the Kicking Horse mine there is a major change in dip, from 25° northeast in the No. 1 area to nearly flat under No. 2 orebody. On both sides of the valley the dips west of the mines steepen abruptly, as the faulted crest of the anticline is approached. South of the Monarch, at the summit of Mount Stephen, dips are to the southeast. A sharp, north plunging syncline may be seen above and just east of the railway tunnel under East Monarch. It is pronounced in the Lower Cambrian strata; the Mount Whyte strata thicken into it, and the Cathedral strata are practically unaffected. These features are illustrated in Figure 3. The east limb is steep and partly faulted, and the quartzites east of the Monarch are 200 feet higher than would normally be expected.

Faulting

The Stephen-Cathedral fault extends from the high col between these two mountains northward down Monarch Creek valley, and across the Kicking Horse River into Yoho Valley. It is a steeply west dipping normal fault, the west side having apparently dropped about 3000 feet, relative to the east. Lower Cambrian quartzites, occurring high on Cathedral Mountain, are found along the railway below the Monarch workings on Mount Stephen. In the course of underground drilling in the East Monarch, and surface drilling east of the Kicking Horse Mine, quartzites were encountered at anomalously high elevations. If these quartzite levels are taken to indicate the location of the Stephen-Cathedral fault plane, the dip has the preposterously low value of 24 degrees. It seems more likely that the small syncline described above is part of a linear disconformity at the top of the Lower Cambrian. Section D in the Monarch (Figure 5) at 1600 feet back from the outcrop, shows that strata at the ore horizon in the Cathedral formation appear to project directly into the Lower Cambrian quartzites, long before the Stephen-Cathedral fault ought to be reached. The same situation obtains east of the Kicking Horse, so that a large section of ground east of the mines, down the dip of the ore horizon, and originally thought to be favourable prospecting ground, is eliminated.

What may be a small branch of the Stephen-Cathedral fault follows the gulley over the east ridge of Mount Field, and shows a vertical offset of 150 feet, with the west side downthrown.



Panoramic view of Mount Field from the West Monarch outcrop.

PLATE 17

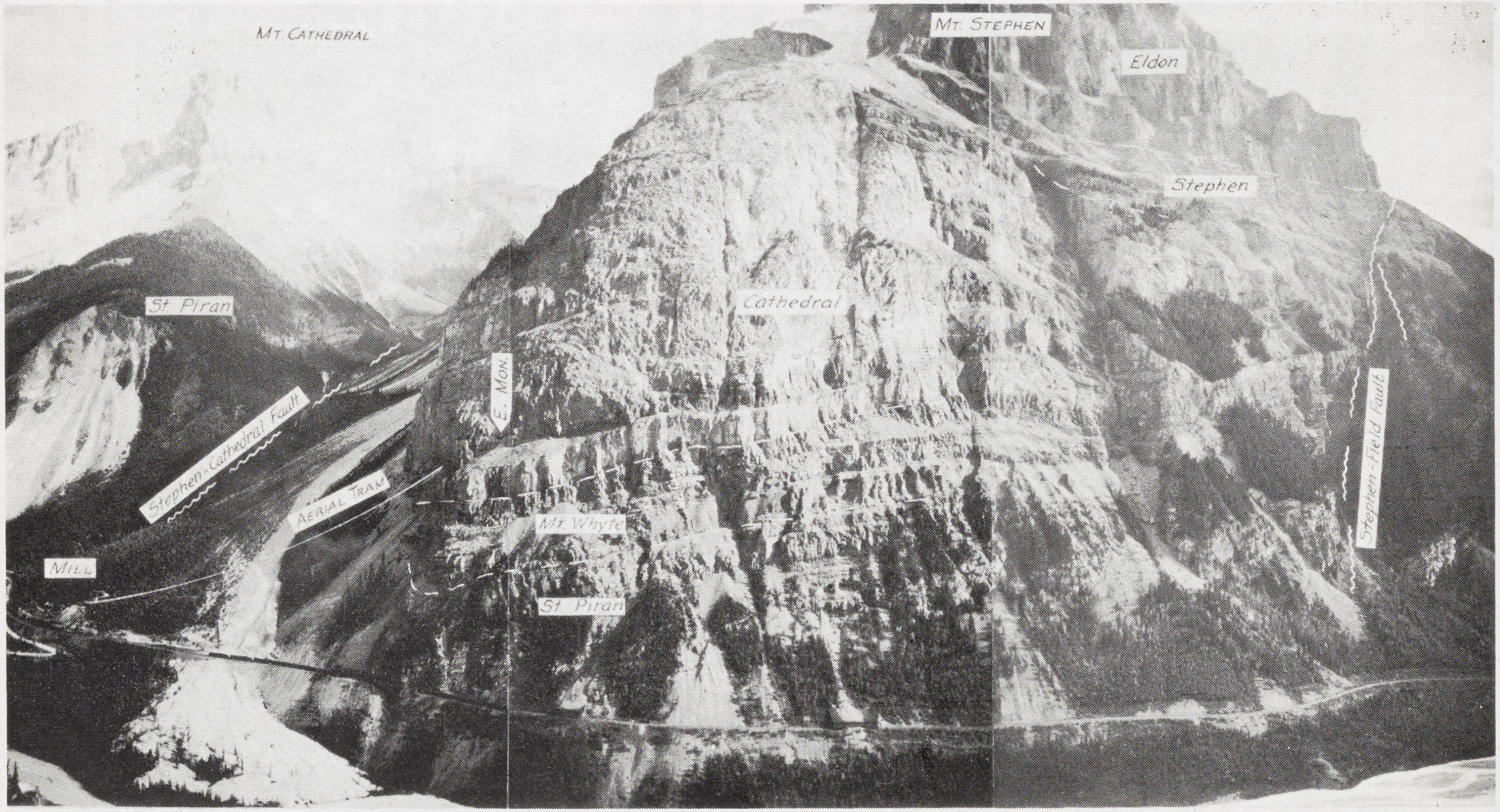


PLATE 18

Panoramic view of Mount Stephen from a point near the upper outcrop of the Kicking Horse ore zone.

PLATE 19

Lenticular, reef-like body of pale, structureless dolomite in Cathedral formation, north side of Kicking Horse Valley west of Sherbrooke Creek. Note concentration of vugs in bands and patches, and sharp upper contact of lens with normal, gray, bedded dolomite. Photograph by M. K. Sorensen.

This fault is of interest because it carries a wide zone of dolomite vein-breccia.

About a mile west of the mines the Stephen-Field fault has a branching and irregular course (N 15°W), marked by gullies on both mountains. It has a steep east dip and a normal vertical displacement of about 1000 feet, the east side being downthrown. It closely parallels the minor anticline, a few hundred feet east of the crest of that fold.

GEOLOGY OF THE MINES

SHAPE AND SIZE OF OREBODIES

Of a considerable diversity of shape and size shown by the orebodies, three characteristic features are apparent. The first is elongation, along consistent linear trends, which lie approximately parallel to the bedding planes. The second is a constancy of horizontal width, or rather the lack of the erratic lateral spreading which might well be expected in a replacement. The third feature is that the width is nearly always several times the thickness. Thus the general shape has been compared to a flattened cigar. The long-axis trend is maintained by component orebodies when a 'run' of ore is discontinuous. In actual size, vertical cross sections mined have varied from as little as 6 x 20 feet to 25 x 140 feet. The latter figure is that of the West Monarch orebody near its outcrop. The maximum cross section for both mines is about 4000 square feet. This was shown by the 150 stope in the East Monarch, but it had a very short length. Because this orebody does not outcrop, it is a notable exception to the theory once held, that the orebodies taper back from their outcrops.

TRENDS

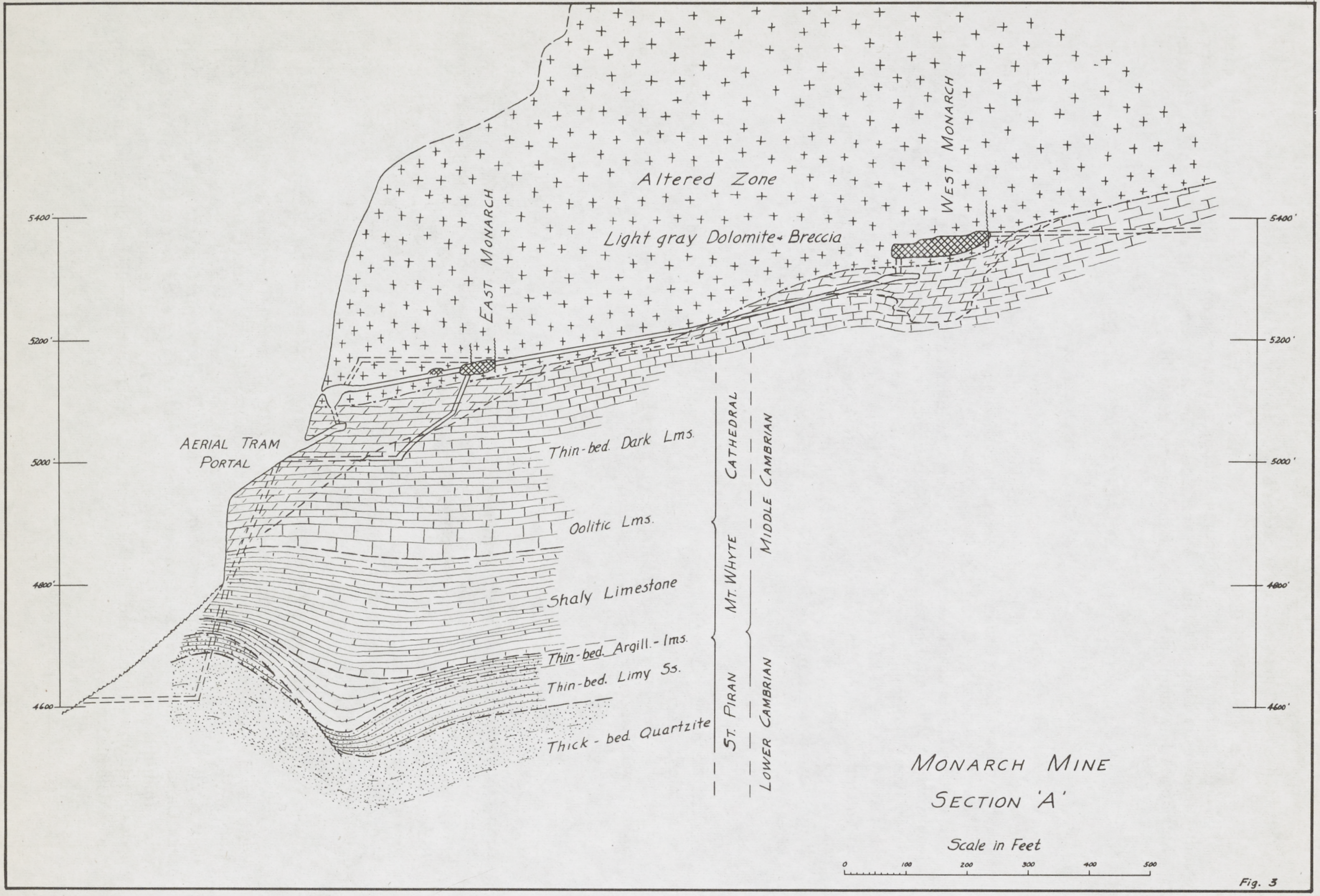
The trends of the orebodies and 'runs' are well shown in Figure 1, and need not be enumerated. There is no simple alignment between the Monarch and Kicking Horse deposits, but possibly the general east boundary of the Monarch area is approximately parallel and collinear with Kicking Horse No. 2 orebody.

STRATIGRAPHIC LOCALIZATION

Instances of mineralization are known from well down in the Mount Whyte formation to the top of the Cathedral formation. The productive ore bodies, however, occur within 200 feet stratigraphically of one another, in the lower 400 feet of the Cathedral formation. The West Monarch orebody is about 380 feet above the shaly limestone member of the Mount Whyte formation, and the East Monarch is 80 to 100 feet lower. The Kicking Horse orebodies are both about 180 feet above the identical member, and thus 100 to 120 feet stratigraphically lower than the East Monarch. In the Monarch mine, generally, the orebodies rise slightly to the south, through the strata; and in the Kicking Horse they drop slightly through the strata, away from the outcrop.

LOCALIZATION WITH RESPECT TO DOLOMITIZATION

The stratigraphic localization is controlled by the position of the base of the dolomitized portion of the Cathedral formation. Throughout most of the mine area there is a sharp interface between the light gray, brecciated, dolomite mass above, and the thin-bedded, black, limestone or partially dolomitized limestone below. This surface is often referred to as the 'Black Dolomite Contact.' The footwalls of all orebodies are either on, or a few tens of feet one way or the other, from this contact, mostly just above it. Downward partial dolomitization into the thin-bedded formation is localized by the orebodies. This feature will be discussed more fully under dolomitization.



Monarch Mine
Section 'A'

Fig. 3

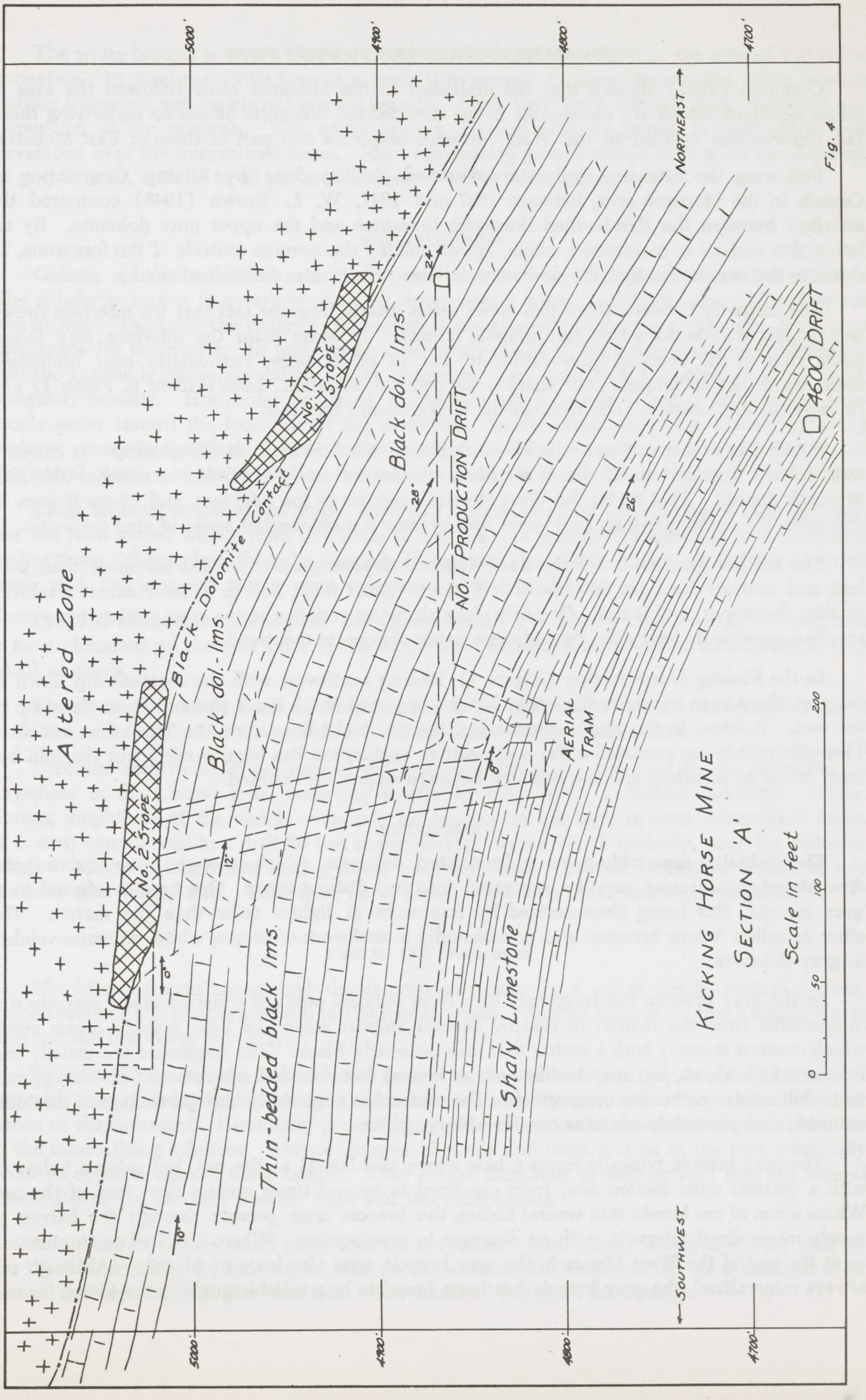

Altered Zone
No. 2 Stope
Black dol.-lms
Black Dolomite Contact
No. 1 Stope
Black dol.-lms.
No. 1 Production Drift
4600 Drift
Thin-bedded black lms
Shaly Limestone
Aerial Tram
Kicking Horse Mine
Section 'A'
Scale in feet
0
50
100
200
← Southwest
Northeast →
5000'
4900'
4800'
4700'
24°
28°
26°
12°
10°
8°

Fig. 4

LOCALIZATION WITH RESPECT TO MINOR FOLDS

Goranson (1937) showed that the orebodies in the Monarch Mine followed the axes of minor synclines, which are discernable in the thin-bedded dolomitic limestone underlying them. His observations applied to the West Monarch orebodies and part of those at East Monarch.

Following the extensive exploratory diamond drilling done by Mining Corporation of Canada in the Monarch area, between 1937 and 1947, W. L. Brown (1948) contoured the interface between the thin-bedded dolomitic limestone and the upper gray dolomite. By relating this surface to a reference plane, approximating the average attitude of the formation, he came to the conclusion that the orebodies followed the crests of anticlinal domes.

The disparity between these two views arises mostly from the fact that the interface Brown was dealing with is not a true stratigraphic horizon. In some cases the interface may follow minor rolls in the bedding quite faithfully, but in other cases, particularly near orebodies, there are abrupt deviations. Also there is the regional deviation, quite evident in Plates 17 and 18, wherein the interface rises through the strata toward the west.

Figure 3 is a cross section of the Monarch 150 to 200 feet in from the outcrop. It shows a well defined syncline under the West Monarch deposit and a shallower one under the East Monarch deposit. That under the West Monarch persists in for 1000 feet, and where it loses its character, the orebody lost its lead value, and became a disconnected series of zinc orebodies.

The shallow syncline under the East Monarch deposit persists inward for more than 2000 feet, and controls the main 200 run of orebodies. Cross folds, and to a lesser extent fractures, localize the stopes on this run. One-fifty stope shows an anticline at one cross section, but a small syncline controls its long axis, the anticline being oblique to this trend.

In the Kicking Horse section (Figure 4), looking northwest with the regional dip down to the east, there is an extensive flat under No. 2 stope, and No. 1 lies a short distance downdip to the east. Relative to the regional structure, the two orebodies are on the flank of an anticline. This relationship has persisted as far northwest as exploration has been carried, but the fold has been found to broaden, and the distance between stopes has doubled.

BRECCIATION

The orebodies invariably occur in brecciated dolomite, which, though presenting a great diversity of appearance, may be separated into two distinct types. One type is referred to as 'gray breccia,' this being characterized by fragments of lighter color than the matrix. The other is called 'white breccia,' and is essentially a stockwork of coarse, white, dolomite veinlets in gray dolomite.

In the gray breccia, the fragments vary from vaguely outlined rounded areas, scarcely distinguishable from the matrix, to sharply defined angular masses of light gray or cream color, which contrast strongly with a matrix that may be nearly black. The fragments are usually less than one inch across, but may be as much as several feet. Both fragments and matrix approximate dolomite in carbonate composition. The matrix has a relatively high percentage of insoluble material, and commonly contains considerable graphite.

The gray breccia typically forms a halo above and lateral to the ore, but seldom below it, with a vertical cross section area from one-third to several times greater than that of the ore. Where a run of ore breaks into several bodies, the breccia zone persists through the barren or poorly mineralized intervals, with no decrease in cross section. Where a run of ore terminates, as at the end of the West Monarch, the gray breccia zone also loses its identity. Although not always mineralized, the gray breccia has been found to be a reliable guide in the search for ore.

The white breccia is very widespread, and can be found anywhere in the altered Cathedral formation. In good ore, white breccia is invariably present to some degree, the white veinlets cutting fragments and matrix of the gray breccia. Here they have effected local transport and deposition of ore minerals. The white breccia, accompanied by pyrite, is particularly well developed over the mineralized areas. Ideal ore-bearing ground would have great development of gray breccia, with 15 to 30 per cent veinlets of white breccia type.

MINERALIZATION

Galena, sphalerite, pyrite, and chalcopyrite are the only recognizable metallic minerals. The sphalerite occurs in a variety of colors, from nearly white to dark brown. All colors are low in iron. Typically the coarsely disseminated ore minerals replace gray breccia, showing a preference for the matrix. In high grade sections all traces of the breccia may be obliterated, and the gangue is coarse, crystalline, white, dolomite. Less commonly the minerals are in short, irregular, veinlets. Horizontal bands of nearly pure ore minerals, a foot or more thick, commonly occur toward the footwalls of the orebodies. In some instances galena extends out along bedding planes in the black, dolomitized, limestone. Mineral values show an abrupt decrease at the lateral margins of the orebodies, but tend to diminish gradually at the ends of the runs.

Large sections of individual stopes have had a fairly constant ratio between lead and zinc, but the ratio varied widely from one stope to another. In general the Monarch ores were four or five times richer in lead than the Kicking Horse ores. Lead-rich bodies always have carried some zinc, but zinc-rich stopes were sometimes almost lead-free.

Pyrite is conspicuous throughout the altered zone. It is a minor constituent of the ores, and is most abundant on the east sides of the orebodies. Chalcopyrite is widely distributed in very small amounts.

The silver in the ores bears no fixed relation to the lead or zinc values. Its concentration in lead ores was found to be three to five times its concentration in zinc ores.

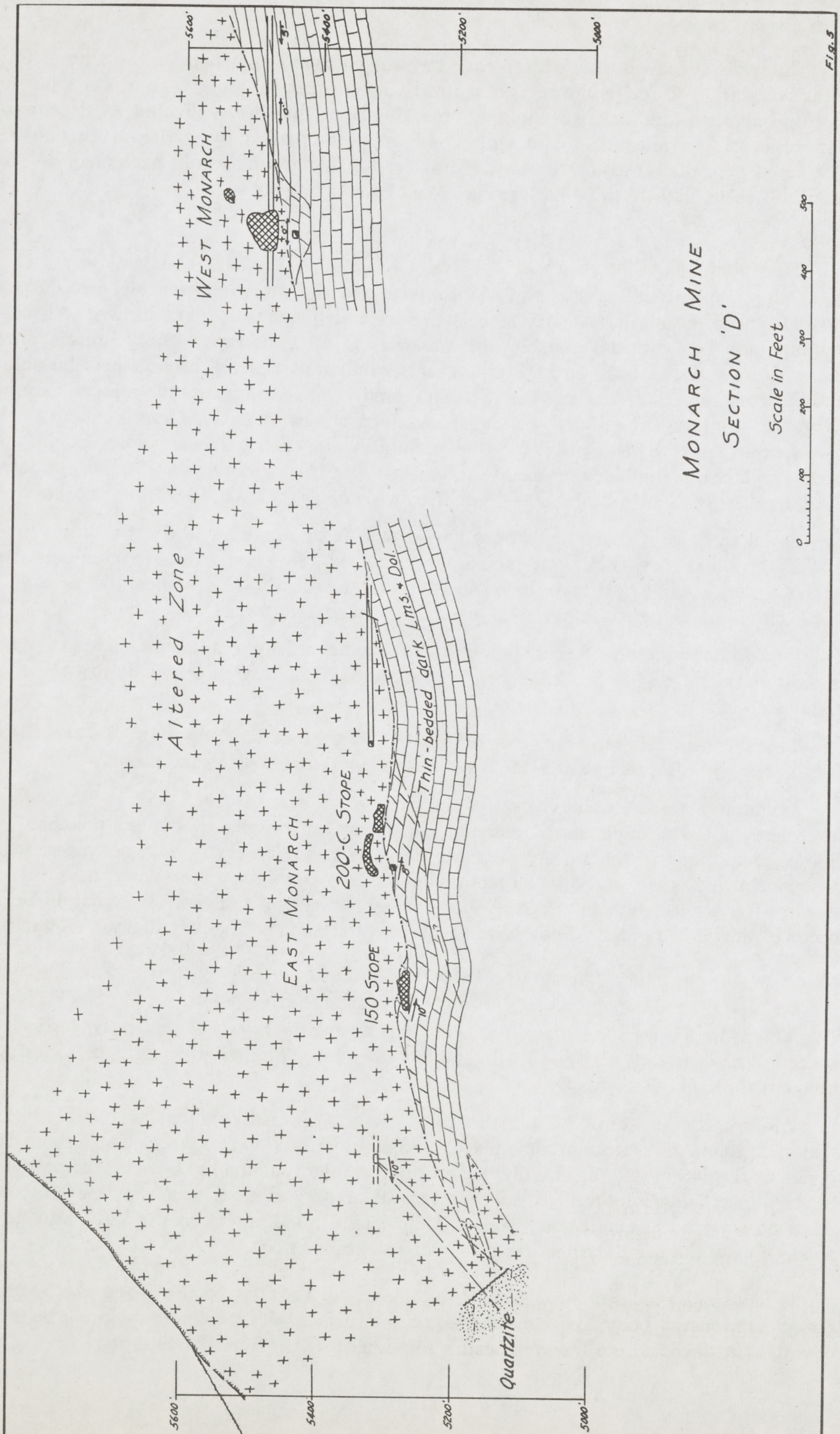
Dolomite constitutes 95 per cent of the gangue. Quartz is very rare in the orebodies or anywhere in the altered zone, occurring mostly in vugs with crystalline dolomite. White, fibrous, amphibole of the variety mountain leather, occurs sparingly in some mineralized areas. It is most conspicuous in a drift 20 feet under Kicking Horse No. 1 orebody, near the outcrop, where it occurs in tough intersecting sheets weighing several pounds. Irregular bodies of talc occur in this vicinity also. They have no apparent relation to the metaliferous minerals.

FAULTS AND FRACTURES

The Monarch runs are crossed almost perpendicularly by a set of nearly vertical fissures, spaced more or less regularly at 100 to 120 foot intervals. Similar fissures in the Kicking Horse runs cut the orebodies obliquely.

Zones in the fissures of a few inches to several feet in width contain clay, boulder-like residual materials, mountain leather in some places, and considerable open space. They show little evidence of displacement. Essentially pre-ore in age, their function has been that of partial barriers to the mineralizing solutions. Abrupt changes of grade and cross section of the ores commonly occur on opposite sides of these fissures. They extend hundreds of feet upward into the altered zone. Below the ore they become tight and less conspicuous.

A few similar fissures trend parallel to the orebodies. One occurs along the west wall of the West Monarch body, and can be seen on the surface. Its relation to the ore is believed to be casual, as it deviates into the west wall a few hundred feet from the outcrop.


West Monarch
Altered Zone
East Monarch
200-C Stope
150 Stope
Thin-bedded dark Lms. + Dol.
Quartzite
5600'
5400'
5200'
5000'
Monarch Mine
Section 'D'
Scale in Feet
0
100
200
300
400
500
Fig. 5

Sets of closely spaced, steeply dipping fractures, forming zones several tens of feet wide, cross some orebodies at a small acute angle. Such zones are associated with the good ore, and appear to have facilitated the replacement process. They extend into masses of ore on a diminished scale and show slight evidence of post-ore movement.

A conspicuous fault striking north 45° west, and dipping 60° northeast, forms a large part of the hanging wall of 150 stope in the East Monarch mine. It carries gneissic galena several feet below the main ore-body. Among the faults in the mine, it alone has the aspect of a possible feeder channel.

Other faults closely follow the bedding planes in the thin-bedded footwall rocks. Generally these show only slight evidence of movement along the carbonaceous-argillaceous partings between the limestone beds, but in the east portion of the Monarch mine, where the formation is more extensively dolomitized, they are definitely faults. The movement is about normal to the general direction of the runs. They are of interest as possible evidence of a low angle thrust movement, as suggested by Goranson (1937) to explain the localization of the base of the altered zone.

DOLOMITIZATION

ORIGIN OF THE DOLOMITE

Many varieties and aspects of dolomitization are to be found in the Cambrian formations of the Bow Range. Much of the dolomite is fine-grained, fairly well-bedded, and stratigraphically persistent. This may be best accounted for by the marine alteration theory of Van Tuyl (1914), though some apparent relations to structure have been observed. The dolomite of the Eldon formation in the vicinity of the mines, and much of that in the Cathedral formation elsewhere, (e.g. on Cathedral Mountain) may be in this category.

The great wedge of dolomite in the Cathedral formation in the vicinity of the mines, however, has several features which suggest a later hydrothermal origin. Bedding is partially obliterated. Only diffuse dark bands remain from the original thin, regular, stratification of the unaltered limestone, and only a few gross stratification planes stand out on the outcrops. Pyrite is common all through the formation, and occurs in all places in the same crystal form (pyritohedron) as is found in the vicinity of the orebodies. Much of the pyrite occurs in veinlets or vuggy masses of coarse crystalline dolomite. The transgressive nature of the basal contact and the fingering out of the western edge of the dolomite wedge also suggest a hydrothermal replacement type of origin.

Half a mile east of the Kicking Horse Mine, dolomite has veined and brecciated the Stephen shales. The small fault in the east gulley of Mount Field has vein dolomite associated with it. The position of the Stephen-Cathedral fault, at the base of the wedge, is also suggestive of structural control of the dolomitization.

It is evident that a considerable amount of the dolomite was formed by hydrothermal activity. The problem is how much. On the basis of obliteration of bedding and discordant contacts only, much of the dolomite of the Eldon formation might be reclassified as a hydrothermal deposit. There are in the Eldon many isolated islands of unaltered limestone with irregular contacts. One such may be seen in Plate 17, under the hump on the east ridge of Mount Field. Irregular dolomitization of this type is conspicuous on Mount Victoria, Mount Temple and elsewhere, in the Cathedral formation. To include all this in the hydrothermal category would raise the problem of the introduction of magnesia on a batholithic scale.

RELATION OF DOLOMITIZATION TO MINERALIZATION

Several features of the deposits suggest a genetic relationship between the dolomite and the mineral deposits. First there is the spatial relation of the deposits to the dolomite-limestone

interface, which has been described earlier. Second is the fact that the gangue of the ore is invariably dolomitic. This is well illustrated in Kicking Horse No. 2 stope, where the orebody overlaps on the west side on unaltered limestone. Irregular vein-like fingers of the orebody extend several feet into limestone. The gangue in these fingers is dolomite. A third feature is the halo of partially dolomitized limestone (50 to 70 per cent dolomite), which is developed under the orebodies. This had the black color and thin-bedding of the limestone, but is recrystallized and pyritic, and weathers reddish brown. It is best developed under the West Monarch and Kicking Horse No. 2 orebodies. Figures 3 and 4 show this relation diagrammatically.

Hewett (1928) described many examples of lead-zinc deposits that are related to dolomitization. The amount of dolomite ranges from thin aureoles around the orebodies to masses, hundreds of times greater in volume than the orebodies. In the latter case, as in this case, it is difficult to draw the line between dolomite related to the ore and that of another origin. It is difficult not to include all of the wedge of dolomite in the Cathedral formation in one category.

MODE OF ORIGIN OF THE DEPOSITS

The hypothesis of hydrothermal origin of the Cathedral dolomite involves broad folding, and the development of the Stephen-Cathedral fault, prior to dolomitization. When dolomitization was well advanced, minor folding and faulting occurred, the Stephen-Field fault probably having been formed at this time. The zones of gray breccia must have formed during or closely following the minor folding. No satisfactory theory, which will account for its gradations and its close association with the folds, can yet be advanced for the origin of the breccia.

Fissuring and development of sheeted zones probably began at about the same time as the minor folding, and continued during deposition of the ore.

Mineralization is thought to have followed closely the development of the breccias, while dolomitization was still in progress along the base of the wedge. Lack of metallic minerals between the runs suggests that the ore solutions advanced longitudinally along them, from some common source in the locale of the present Kicking Horse Valley, a source now eroded away. The isolation of some orebodies lessens the credibility of this theory. It is also possible that the solutions migrated upward along the bedding planes from east to west, originating in common with the dolomite forming solutions, in some deep seated structure such as the Stephen-Cathedral fault.

The minor folds and associated gray breccia zones were the principal factors controlling deposition. Fractures merely facilitated replacement where they crossed these zones. The transverse fissures appear to have had little effect, except locally to impede the progress of the ore-solutions. Minor movements on some fractures occurred after the ore was solidly emplaced.

The mineral assemblage and rock alteration place the deposits in the low temperature category. There are many points of similarity between the Field deposits and those of the Southeast Missouri Lead District.

REFERENCES

Allan, John A. (1914): Geology of Field Map-Area, B.C. and Alberta; Geol. Surv., Canada, Memoir 55.

Brown, W. L. (1948): Monarch and Kicking Horse Mines; Can. Inst. Min. Met., Symposium on Structural Geology of Canadian Ore Deposits, pp. 231-237.

Goranson, E. A. (1937): Geology of the Monarch and Kicking Horse Ore Deposits, B.C.; Economic Geology, Vol. XXXII, No. 4.

Hewett, D. F. (1928): Dolomitization and Ore-Deposits; Economic Geology, Vol. XXIII, pp. 821-863.

Ney, C. S. (1951): Ore Deposits at Field, B.C.; Western Miner, Vol. 24, No. 6.

Rasetti, Franco (1951): Middle Cambrian Stratigraphy and Faunas of the Canadian Rocky Mountains; Smithsonian Miscellaneous Collections, Vol. 116, No. 5.

Van Tuyl, F. M. (1914): The Origin of Dolomite; Iowa Geological Survey, Vol. XXV, Annual Report, pp. 251-422.

Walcott, C. D. (1908): Cambrian Sections of the Cordilleran Area; Smithsonian Miscellaneous Collections, Vol. 53, No. 5, pp. 204-220.

IGNEOUS ROCKS IN THE SOUTHERN ROCKY MOUNTAINS OF CANADA[1]

H. C. GUNNING[2]

INTRODUCTION

The index map accompanying this guide book (Map 2.) shows the areas in which intrusive rocks have been mapped in the southern Canadian Rockies. It also shows the places where flows of Purcell lava have been distinguished, and similarly, localities where the extrusive rocks of the Crowsnest formation are known to be present. Near the former there are, in many places, dykes and sills of diorite, that have been observed but not mapped. To the writer's knowledge no intrusive rocks have been found associated with the Crowsnest volcanics.

The reader must bear in mind the fact that the interior part of these mountains, between the Ice River district and the Crowsnest area, is largely unmapped.

ICE RIVER COMPLEX

The Ice River Complex is the largest and best known of the intrusive bodies in the Canadian Rocky Mountains. Indeed, many reports have referred to it, by implication at least, as the only intrusive mass. A description of it is provided elsewhere in this volume. It is an alkaline complex that lies twelve to sixteen miles south of Field, British Columbia. The total area of its outcrop is about twelve square miles, the maximum length of exposure being about seven miles, and the maximum width about four miles. Two intrusive bodies are exposed. The smaller of these has a surface area of about two square miles, and the larger, ten square miles. To Allan (1914) the exposures exhibit similarities to, and a considerable degree of departure from true laccolithic form. He (1914) distinguished three main types of rock in the complex, but emphasized that there are gradations between all varieties:

1. Leucocratic Types (alkalic types): nephelite syenite, sodalite syenite, etc.
2. Transition Types: ijolite, urtite, etc. (mesocratic types in part).
3. Melanocratic Types: jacupirangite and other black rock types.

Allan pointed out that the intrusion was later than the folding of the sedimentary strata in this part of the Rockies, and therefore, in his opinion, post-Cretaceous. Ellsworth and Walker (1926) described knopite, a ceriferous perovskite, from a pegmatite dyke on Moose Creek.

INTRUSIVE ON CROSS RIVER

In 1886 G. M. Dawson described a body of diorite on Cross River, a tributary of the Kootenay River, some fifty miles southeast of the Ice River Complex. This body has been visited by several geologists in recent years, but no new descriptions have been published.

Dawson (1886) said:

"From the immediate vicinity of the summit of the (White Man's) pass, westward to the mouth of the North Fork (of Cross River), the limestones, both in the bottom of the valley and so far as could be observed, to the tops of the adjacent mountains, have become changed to marble, which is in some places very coarsely crystalline . . . More or less pyrite and grains of magnetite are generally disseminated through the rock, and in all the streams a great abundance of crystalline vein-matter, calcareous, dolomitic, or silicious, was noticed. Though no metalliferous minerals of value were noted, this appears to be a locality worthy of the attention of the prospector, on account of the extent and character of the local metamorphism. In no other

[1] See map, page 117.
[2] Dean, Faculty of Applied Science, University of British Columbia. The writer is indebted to W. H. Mathews for discussion of some parts of the material contained in this paper.

place in the mountains were the limestones observed to be altered over so extensive an area. The cause of the alteration is obscure. It is accompanied by no evidences of special mechanical violence, as the beds west of the summit dip southwestward at low, regular angles, nearly equalling that of the slope of the valley, and further down, become nearly horizontal, or show very light north-easterly dips. There is reason to believe, however, that an intrusive mass, resembling that subsequently described, may here nearly approach the surface, though it has not actually been exposed by denudation . . .

"At the mouth of the second tributary below the North Fork, on the same side, are numerous large masses of greenish-grey diorite (?) somewhat resembling the intrusive of Ice River but apparently not, like that, a nepheline-syenite. These have been derived from an intrusion of the same material, against which the limestones rise to an angle of 45 degrees, and form the steep western edge of the synclinal just mentioned. The area of the intrusive may be extensive to the north of the valley of the pass. Associated with it and cutting the diorite, are quartz veins, carrying copper pyrites, but on assay by Mr. Hoffmann, these proved to contain neither gold nor silver."

One of the more recent investigators[1] reports that the intrusive is a sill-like body, not exceeding 200 feet in thickness, that cuts limestone and slate dipping 60 degrees northeast. It lies on the northeast side of Ram Creek, and contains numerous small, discontinuous veins, of quartz, calcite, and chlorite, with a minor amount of chalcopyrite. Apparently the outcrops are on the east limb of a relatively minor anticline.

INTRUSIVES NORTHEAST OF CRANBROOK, BRITISH COLUMBIA

Precambrian strata of the Purcell series are exposed along the western front of the Rocky Mountains, northeast of Cranbrook, for about thirty miles from Bull River to Lussier (Sheep) River. In this region the Fort Steele and Aldridge formations (of early Beltian age) are intruded by two major and several smaller sill-like bodies of the Purcell diorite. East of Wild Horse River the Siyeh formation, of rather later Beltian age, is overlain by Purcell lava. Rice (1937) believes that the diorite intrusions are related to the lavas, and therefore are Precambrian in age. Dykes of diorite are also present. The normal diorite consists of about 50 per cent amphibole, 40 per cent plagioclase (varying from oligoclase to acid labradorite), 4 per cent quartz, 2 per cent magnetite or ilmenite, and 4 per cent accessory minerals. "Granitic" phases, that are found along the upper margins of some sills, have been ascribed to magmatic differentiation by Daly (1912) and by Schofield (1915), but Rice (1937) suggested that they may be due to granitization of sediments. Swanson has described these metamorphic effects, around Kimberley, in excellent detail (1945).

In this same part of the Rocky Mountains there are other intrusives, in the form of dykes and small, irregular bodies. Rice (1937) says of them:

"Small syenite dykes are very common in the area east of Kootenay River. These dykes do not exceed fifty feet in width and are, consequently, too small to be shown on the map. They occur all through that part of the Rocky Mountains within the map-area and are especially abundant on Lakit and Boulder Creeks . . . Two larger bodies of syenite occur outside the map-area; one on the east fork of Wild Horse River and another, a small stock, on the plains near the mouth of Bull River, southeast of the map-area . . .

"The syenite dykes, where unaltered, are white, pink, or grey, and vary from extremely fine grained to coarsely porphyritic rocks. They are all sodic and grade in composition from monzonites to syenites and quartz syenites.

[1] Thompson, R. M., personal communication.

"The principal constituents are potash feldspar (orthoclase and microcline) and plagioclase. The primary plagioclase probably varies from andesine to oligoclase, but most of the specimens show a considerable amount of clear, secondary albite . . ."

Rice points to the heavy alteration of many of the syenite dykes in the Rockies, chiefly to fine grained chlorite, talc, epidote rocks, and suggests that the syenites are probably of early Tertiary age.

A short distance north of Cranbrook map-area, near the Estella mine on Tracy Creek, there are dykes and some stocks of similar syenitic rocks. Hedley (1952) mentions one such body at the mine. "Greenstone" dykes, in addition to syenite, occur at the Kootenay King mine, on Wild Horse River. The greenstone is older than the syenite.

The small stock on Bull River, referred to by Rice (1937), was mentioned by Dawson (1886) as follows:

"North of the Bull River, near the trail which leads to the bridge, and not far from the base of the mountains, a low, isolated hill was found to be composed of a remarkable crystalline rock, which is evidently intrusive. It is chiefly composed of well-formed orthoclase crystals, which are pink in colour, and, in some cases, nearly an inch in length. The rock is rather porous, owing to the decomposition which it has suffered, and its jointage-planes are coated with rusty incrustations and micaceous hematite. It may be regarded as a variety of quartz-porphyry in which the quartz is, however, visible only under the microscope. As loose pieces of similar material were found in Elk River, it is possible that other similar intrusions occur elsewhere in the neighborhood."

PRECAMBRIAN ROCKS NEAR THE INTERNATIONAL BOUNDARY

The index map shows areas of Precambrian strata near the International Boundary, and indicates the presently known extent of the Purcell lavas, as they have been shown on published maps. Diorite dykes and sills (Purcell intrusives) were mapped by Daly (1912) just south of the International Boundary, and there are many references to sills north of the border, but they have not been shown on published maps. Hume (1933) studied the area between Waterton Lakes and Flathead River and said:

"The Kintla can readily be divided into four divisions which in order from youngest to oldest are as follows: (4) Gray argillites with small amounts of red argillites and containing at least three porphyrite sills."

The Kintla is the youngest Precambrian formation exposed and lies above the Purcell lava. Hume also reports a prominent diorite sill in the Siyeh formation on Mount Lineham, and thence to North Kootenay Pass. Hage (1943) mentioned two diorite sills in the Kintla formation and one in the Siyeh. In the Carbondale River area two diorite sills are mentioned as occurring in the Precambrian strata, one in the Siyeh formation, and an upper one "near the Precambrian-Cambrian contact," (Clow and Crockford, 1951). It is obvious that the dioritic intrusives cannot have been strictly contemporaneous with the Purcell lava, nor have been merely feeders for it, since they are found in beds above the lava and indeed almost up to the contact with overlying Middle Cambrian (?) quartzite. This contact is "apparently conformable" (Clow and Crockford, 1951) in the Carbondale River area, where the oldest fossils found are thought to be of Upper Devonian age. In the Beaver Mines area the contact is said to be unconformable, and Middle Cambrian fossils have been found.

CROWSNEST FORMATION

The Crowsnest formation is an assemblage of agglomerate, tuff, and ash beds, rich in feldspar and analcite, with a few thin flows of lava. It attains its maximum thickness of about

1100 feet in the vicinity of Coleman, and exhibits thinning in all directions from this locality (Clow and Crockford, 1951). J. D. MacKenzie (1914) thought that the eruptive source was probably a series of small cones, presumably in the vicinity of Coleman. To the writer's knowledge none of these has been identified, but no intrusive rocks associated with the ejectamenta have been discovered. Evidence in the Carbondale River area suggests that the Crowsnest formation is of late Lower Cretaceous age.

REFERENCES

Allan, John A. (1914): Geology of the Field Map Area, B.C. and Alberta; Geol. Surv., Canada, Memoir 55.
Clow, W. H. A. and Crockford, M. B. B. (1951): Geology of Carbondale River Area, Alberta; Res. Council of Alberta, Rept. 59.
Daly, R. A. (1912): Geology of the North American Cordillera at the Forty Ninth Parallel; Geol. Surv., Canada, Memoir 38, part 1, Chap. X.
Dawson, G. M. (1886): Preliminary Report on the Physical and Geological Features of that Part of the Rocky Mountains between Latitudes 49° and 51°30′; Geol. Surv., Canada, Ann. Rept. 1885, B, p. 116.
Ellsworth, H. V. and Walker, J. F. (1926): Geol. Surv., Canada, Summ. Rept. 1925, A., p. 230-232.
Hage, C. O. (1943): Beaver Mines; Map 739A; Geol. Surv., Canada.
Hedley, M. S. (1952): B. C. Minister of Mines. Ann. Rept., p. 187.
Hume, G. S. (1933): Geol. Surv., Canada, Summ. Rept. 1932, B, p. 6.
MacKenzie, J. D. (1914): The Crowsnest Volcanics; Geol. Surv., Canada, Mus. Bull. 4, Geol. Ser. 20.
Rice, H. M. A. (1937): Cranbrook Map Area, B.C.; Geol. Surv., Canada, Memoir 207.
Schofield, S. J. (1915): Cranbrook Map Area, B.C.; Geol. Surv., Canada, Memoir 76.
Swanson, C. O. and Gunning H. C. (1945): Sullivan Mine; Trans. Can. Inst. Min. Met., vol 48, pp. 645-667.
Walker, J. F. (1926): Windermere Map Area, B.C.; Geol. Surv., Canada, Memoir 148, p. 18 and Fig. 2.

ICE RIVER IGNEOUS COMPLEX

JOHN A. ALLAN[1]

PREFACE

I have been asked by Dr. J. C. Sproule, on behalf of the Alberta Society of Petroleum Geologists Field Conference Committee, to prepare this paper on the Ice River igneous complex for the A.S.P.G. Field Conference, to be held at Banff on August 27 and 28, 1954. This request was based on the fact that during the years 1909 to 1916 I had mapped, on behalf of the Geological Survey of Canada, the geology in a belt adjacent to the main line of the Canadian Pacific Railway across the Canadian Rocky Mountains, from the east face of the mountains east of Banff, west to Golden, British Columbia in the "Rocky Mountain Trench." The field excursion will traverse the part of this section extending from Banff to Kicking Horse Pass, Field and Golden.

In this area mapped, special attention was given in 1909 to 1912 to the Ice River Complex, and included field exploration, mapping and laboratory investigations. The results were published in 1914 by the Geological Survey of Canada, as Memoir 55 (1), and as International Geological Congress Guide Book 8, Part 2 (2).

The details in this paper are taken from Memoir 55, published in 1914, forty years ago. No later field work or petrographic studies have been done on the somewhat unusual igneous rocks in the Ice River Complex.

INTRODUCTION

The Ice River Complex, consisting almost entirely of alkaline rocks, outcrops mainly in the Ice River valley and in the upper end of Moose Creek valley.

The Ice River district lies on the western slope of the Rocky Mountain system, in the vicinity and especially south of the main line of the Canadian Pacific Railway in British Columbia between Field and Golden.

Ice River valley extends from Hanbury glacier in a south-southeasterly direction between Chancellor Peak (10,600 feet) and the north and south towers of Mount Goodsir (11,676 feet). Ice River joins Beaverfoot River about eight miles southeast of Wapta Falls, where the Beaverfoot River joins Kicking Horse River, about twenty-five miles upstream from Golden.

Ice River valley is reached by a road, formerly a good pack trail, from the Field-Golden highway, where the highway crosses the Kicking Horse River between Ottertail and Leanchoil. The distance from the highway to the crossing of Ice River is about twelve miles. This trail, formerly known as the "Kootenay trail," has been used for more than a century, and was originally used by the Stony and Kootenay Indians enroute up the Beaverfoot and down the Kootenay valleys to Fort Steele, north of Kimberley, British Columbia.

The early exploration of the Ice River district may be of some interest to readers. In 1841 Sir George Simpson (3) crossed the Kicking Horse Pass and travelled down the river of the same name on his way to the Pacific coast. He may have travelled the Kootenay trail from what is now Leanchoil.

In 1858 the Palliser expedition explored the Rocky mountains at various latitudes. Dr. James Hector (4), geologist to the expedition, crossed the Vermilion pass, followed down the Vermilion River, and up the Kootenay, down the Beaverfoot and up the Kicking Horse River to the continental watershed.

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The main line of the Canadian Pacific Railway was constructed in the early eighties, when further exploratory work was done.

The first geological report of this part of the Rockies was made by G. M. Dawson in 1885. His observations are included in a preliminary report which appeared in the annual volume of the Geological Survey for that year. He made a hasty trip to the mouth of Ice River (5), and noted the intrusive mass and the occurrence of sodalite.

During the following year R. G. McConnell worked out a geological section across the Rocky Mountain belt in the vicinity of the 51st parallel (6).

The specimens of igneous rock collected by Dawson in the Ice River valley were later examined, in 1902, by A. E. Barlow, who published a short description of the diverse types represented (7).

In the same year Prof. T. G. Bonney examined and described sodalite syenite, which had been collected in 1901 by Mr. E. Whymper from the same locality (8).

In 1903, Bonney described certain peculiar markings which occurred in specimens of quartzite, collected by Prof. Collie, from the Canadian Rockies near Field (9).

In 1907, C. D. Walcott began his studies of the Cambrian in British Columbia. He found the best exposed section to be in Mount Bosworth at the Continental Divide, on the Canadian Pacific Railway. He subdivided the series into ten formations, and measured sections in various localities east of Field. He continued his studies in 1909 to 1912 (inclusive) in the vicinity of Field, giving special attention to the palaeontology. He discovered many remarkable fossils, and has greatly extended our knowledge of the fauna that lived in the Cambrian seas. The results of his studies on the Cambrian of this district are published in the Smithsonian Miscellaneous Collections (10).

The writer spent the field seasons of 1910 and 1911 in this district; the preliminary reports have been printed in the summary reports of the Geological Survey of Canada for the same years.

DESCRIPTION OF THE IGNEOUS COMPLEX

Form of Intrusion

This igneous complex comprises an area of about 12 square miles, and is best exposed in the southern part of Ice River valley. The outline of the exposure of the igneous rock is shaped somewhat like a retort, with its greatest development towards the south, and extending from the corners, two arms which narrow down towards the north.

The form of the complex has been interpreted as an asymmetrical laccolith, thinning out towards the north. It has a stock-like conduit through which the molten material was forced from a deeper intercrustal reservoir, that has not yet been exposed by erosion. It agrees with the mechanics of laccolithic intrusion, in the fact that the cover has been lifted to a certain degree by the pressure behind the magma.

Rock Types

Lithologically the rock series comprising the laccolith is alkaline in composition. The material in this laccolithic chamber has been brought in by a single intrusion, and the separation of the magma into the diverse types has resulted from various processes of differentiation.

For convenience in the descriptions of the petrology of the rock types, the series has been subdivided into three groups according to mineralogical composition. The first group includes the leucocratic types, which make up the largest part of the complex. Nephelite syenite is the

most important member, and at the same time the most highly alkaline. With it are included many minor types, all facies of the nephelite syenite.

Within the second group are included ijolites, urtites, and other varieties essentially mesocratic, but varying towards both leucocratic and melanocratic types.

The third group includes the jacupirangites, alkalic pyroxenites, and associated melanocratic varieties.

The texture of the rock varies greatly, not only within the complex as a whole, but also within the groups, and even within the diverse types.

It is a characteristic feature that the rocks vary both in appearance and mineralogical composition, in some places within a distance of a few feet. Irregular patches or schlieren, consisting of material richer in dark colored constituents, are present in many of the types.

Mineralogy of Rock Types

Mineralogically, the groups are characterized by the presence or absence of certain essential minerals. In the first group alkali felspar, nephelite, aegirite, and sometimes sodalite, are the essential minerals. Several varieties of felspar are represented, but orthoclase or microcline and albite, commonly perthitically intergrown, are the most abundant. In the leucocratic rocks, nephelite is always subordinate in amount to the felspar, and in some types, is almost accessory. With the characteristic aegirite—augite is sometimes found accessory amphibole, determined as basaltic and barkevikitic hornblende. Sodalite is an essential constituent in some of the materials, which has been concentrated along the roof of the laccolith. This mineral has a deep blue color, so that when it is found as one of the constituents, it makes a decorative stone of economic importance. Sodalite is also present in veins that are almost pure.

In the second group, that is the ijolites and urtites, the essential minerals are nephelite, aegirite-augite and barkevikite. Felspar is either absent or accessory. In some varieties of ijolite hornblende predominates over pyroxene, so that it gives a new type, "barkevikite-ijolite." In the transition types from nephelite syenite to ijolite, there is a gradual decrease in the amount of felspar, and a corresponding increase in the amount of nephelite present.

In the jacupirangite and associated types of the third group, there is quite a lot of accessory light colored material. Pyroxene, magnetite, ilmenite, schorlomite, and sphene are essential minerals. In one type of rock, sphene makes up about 30 per cent of the whole.

There is a remarkable absence of dikes in and about the complex. Only twelve were found in the field; these are narrow and most of them have a general east-west trend.

Structure

Structurally, the diverse types of the complex are transitional into one another, and represent a single period of intrusion. In every case the leucocratic types remained in a molten condition after some of the darker colored material had frozen. This latter material was broken, and the cracks filled with the still fluid nephelite syenite. These dike-like masses of light colored rock in the melanocratic material form a striking feature in certain parts of the complex, as they stand out as irregular sheets on the eroded surfaces.

Origin and Metamorphism

The hypothesis offered for the explanation of the diverse types within this complex, which are transitional into one another, is a combination of the result of separation by gravitative adjustment, and a rapid cooling of a part of the original heterogeneous magma in the thinner

and cooler portions of the chamber. There has been a sinking of the heavier minerals, and a rising of the lighter ones. This explains the occurrence of sodalite rich rocks only at the upper contact.

It has been shown that a laccolith, besides arching up the cover, is able to shatter the contact and enclose xenoliths, and even to assimilate a certain amount of the rock on the contact. The main evidence at hand for assimilation is the common presence of calcite as a pyrogenetic mineral. Limestone on the contact has been fused up, and the calcite has crystallized out in a way similar to that of any of the other constituents.

The zone of metamorphism is very irregular and ill-defined. In some places it is only a few feet wide, whereas in other parts the rock is distinctly metamorphosed for 500 to 700 feet from the contact. The most striking contact rock is a dense, reddish brown, hornfels, which lies between the igneous rock and the limestone in the upper contact. This band was originally a calcareous shale, which has become thoroughly baked by the intrusion.

Age

The age of the intrusion, as nearly as can be determined from the evidence at hand, is probably post-Cretaceous, and prior to the Laramide revolution. It is older than the main period of deformation, which is connected with the revolution at the close of the Laramie. There was a period of folding earlier than the main shearing, and the intrusion is younger than this folding.

In the eastern part of the Rocky Mountains the Cretaceous lies conformably upon the older strata, so the assumption is made that the folding occurred after the deposition of the Cretaceous, and is therefore late or post-Cretaceous in age. The period of faulting followed the main deformation of the strata. The Ice River Complex has not been strongly affected by the Laramide revolution. The igneous rocks are so much more resistant than the surrounding sediments that the latter have been intensely squeezed about the igneous mass.

Summary

1. The Ice River intrusive complex has the form of an asymmetrical laccolith with a stock-like conduit. It is believed to be satellitic to a much larger reservoir.

2. The rocks making up the complex are all alkaline in composition, ranging from a nephelite syenite and sodalite syenite at the one end of the series, through urtites and ijolites, to a jacupirangite or alkali pyroxenite at the other end. These diverse types represent a complete petrographic series with intermediate variation facies.

3. The highly alkaline composition of these igneous rocks is believed to have resulted from the desilication of a more acid magma by the absorption of carbonate rocks. In order to assume its present position, the magma had to cut through several thousand feet of carbonate sediments.

4. The diverse rock types within the complex are explained as the result of differentiation from a heterogeneous magma. Gravity caused the denser minerals to sink, while the lighter and more volatile material rose to the top of the chamber.

5. The age of the intrusion is placed as post-Cretaceous, as determined by structural and correlation evidence.

6. There has been a period of folding prior to that of intense orogenic disturbances, which highly sheared the sedimentary strata in this part of the Rocky Mountains.

7. There are two main systems of normal faulting, both of which are younger than the period of intense compression.

8. Upper Cambrian strata are most closely associated with the complex. In the Field map-area a complete Cambrian section has been obtained with a measured and estimated thickness

of more than 18,500 feet. This is the thickest yet measured in Canada. The total thickness of sedimentary strata in this area exceeds 25,000 feet.

9. Three new formations have been recognized and named, two belonging to the Upper Cambrian (Chancellor and Ottertail), and the third to the Lower Ordovician (Goodsir).

REFERENCES

1. Allan J. A: Geology of the Field Map-Area, B.C. and Alberta; Geol. Surv., Canada, Memoir 55, 1914.
2. International Geological Congress; Guide Book 8, Part 2, 1913, p. 189.
3. Simpson, Sir George: Narrative of an Overland Journey Round the World; London, 1847.
4. Hector, James: Quart. Jour. Geol. Soc., London: Vol. 17, 1860; p. 388.
5. Dawson, G. M: Annual Report; Geol. Survey, Canada; Vol. 1, Part B, 1885.
6. McConnell, R. G: Annual Report; Geol. Survey, Canada, Part D, 1886.
7. Barlow, A. E: Nepheline Rocks of the Ice River, B.C.; Ottawa Naturalist, Vol. 16, 1902, p. 70.
8. Bonney, T. G: On a Sodalite Syenite (Ditroite) from Ice River, B.C.; Geol. Mag., Vol. 9, 1902, p. 199.
9. Bonney, T. G: Markings on Quartzite Slibs; Geol. Mag., Vol. 10, 1903, p. 291.
10. Walcott, C. D: Cambrian Geology and Palaeontology; Smithsonian Misc. Coll., Vol. 53, Nos. 1, 5, 1908; No. 7, 1910; Vol. 57, No. 1, 1910; Nos. 2, 3, 5, 1911; Nos. 6, 7, 8, 1912.

PRINCIPAL HOT SPRINGS OF THE SOUTHERN ROCKY MOUNTAINS OF CANADA[1]

B. J. PICKERING[2]

INTRODUCTION

Hot and warm mineral springs are known throughout the Canadian Rocky Mountains, from the Hughes Range to the Liard River. They are commonly associated in groups. The relationship of these groups to geologic structure is in some cases quite apparent, in others wholly obscure.

The best known groups of springs are those at Banff, and the Miette at Jasper, in Alberta, and at Fairmont and Radium, in British Columbia, where the waters are used in swimming pools, which are among the attractions for vacationers. Lesser groups are known in the Hughes and Stanford Ranges, and within the whole area considered in this guidebook the total number of hot and warm springs may well run into several score. A short account of the springs within the vicinity of the route of the field trip follows.

BANFF HOT SPRINGS

The springs at Banff are located on the northeast slope of Sulphur Mountain, in a line nearly parallel to the ridge. Their disposition suggests that they are probably related to the Sulphur Mountain fault, on which Devonian beds have been thrust over the Triassic Spray River formation. The Upper Hot Springs and the Cave and Basin Springs have been placed under government control, and they provide water for the public swimming facilities. The other springs are in their natural state.

The Upper Hot Spring is the highest and hottest spring of the Sulphur Mountain group, emerging at an altitude of 5,196 feet, and having a temperature of 115° Fahrenheit. The spring rises in a shallow well which was dug to control the water supply. The water is distinctly sulphurous, and banks of calcareous tufa surround the spring. A smaller spring, the Kidney Spring, rises in a small depression about 200 yards from the upper spring. The water of this spring is as hot as that of the upper one, but the flow is smaller.

The Middle Springs, between the Upper Hot Spring and the Cave and Basin Springs, are in their natural state. There are two springs, one rising in a pool in a small cave, and the second emerging from beneath a rock at the mouth of the cave.

The lowest of the springs are the Cave and Basin Springs. They were first observed when surveyors for the Canadian Pacific Railway noticed a cloud of vapor rising from a point on the slope of the mountain. The Cave Spring rises with considerable force from the sandy floor of a cave, about 40 feet wide and 20 feet high. The temperature of the water is about 94° Fahrenheit, and the taste and smell are sulphurous. The Basin Spring is only a few feet from the Cave Spring. (At the opposite end of the swimming pool.) It rises into an open rock basin and forms a pool about 30 feet wide.

A small spring rises at the western edge of the Vermilion Lakes, on the Banff-Lake Louise highway, and another on Fortymile Creek, between Mount Norquay and Mount Brewster. These un-named springs are not known to be related to any major geologic structure.

Reference should be made to Warren (1927) for analyses of Banff Hot Springs waters.

[1] See map, page 117.

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RADIUM HOT SPRING

Radium Hot Spring is located beside the Banff-Windermere highway, ninety miles west from Banff, and one mile east of Radium junction. The water from this spring is used in two swimming pools; in one it is maintained at 113° Fahrenheit, and in the other it is cooled to 90° Fahrenheit. The water is non-sulphurous and consequently pleasant for swimming.

The spring emanates from shatter zones within the Jubilee formation, of late Cambrian age. The shattering presumably was caused by the Redwall fault, which crosses the highway about 300 feet east of the spring.

FAIRMONT HOT SPRINGS

Fairmont Hot Springs were first mentioned in print by George Simpson, in his "Narrative of an Overland Journey Around the World," published in 1847. They are situated one and a half miles northeast of the north end of Columbia Lake, on the western slope of the Stanford Range. One spring is located about 300 yards northeast of the swimming pool, at an elevation of approximately 3,500 feet. The water from this spring is used in the pool. A second spring which rises a quarter-mile west of the pool has been left in its natural state. A deposit of calcareous tufa has been formed around each spring.

Following is a table showing the contents of water from the Fairmont and Radium Hot Springs.

	FAIRMONT HOT SPRINGS		RADIUM HOT SPRINGS
	Upper Spring	Swimming Pool spring	Hot Spring
	Raw and Finished Water	Raw and Finished Water	Raw and Finished Water
Sampling Point	Pipe leaving ground	Intake to Pool	Intake at Pool
Date of collection	July 9/49	July 19/49	July 11/49
Storage period (days)	27	18	48
Sampling temperature °C	45.0	33.0	46.5
Test temperature °C	26.8	27.3	24.0
Dissolved oxygen			
Carbon dioxide (CO_2)		(50)	(32.0)
pH	6.7 (6.3)	7.7 (7.0)	8.0 (6.8)
Colour	1 (5)	5 (5)	0
Turbidity	0.3		0.3
Suspended matter, dried at 105°C			
Suspended matter, ignited at 550°C			
Residue on evaporation, dried at 105°C	2145	1218	747
Ignition loss, ignited at 550°C	238	195	138
Specific conductance (micro-ohms at 25°C)	294	1514	834
Calcium (Ca)	441	228	130
Magnesium (Mg)	109	75.2	36.3
Iron (Fe) Total			
Dissolved	0.06	0.09	0.06
Sodium (Na)	34.0	17.8	15.7
Potassium (K)	5.3	3.3	3.2
Carbonate (CO_3)	0 (0)	0 (0)	0 (0)
Bicarbonate (HCO_3)	706 (693)	532 (549)	142 (207)
Sulphate (SO_4)	902	570	356
Chloride (Cl)	38.3 (41.8)	22.6 (46.6)	11.3
Fluoride (F)		0	0.5
Nitrate (NO_3)	Trace	Trace	0
Silica (SiO_2) Gravimetric	21	15	32
Colorimetric	27	18	37
Carbonate hardness as ppm $CaCO_3$	578 (568)	354 (450)	116 (170)
Non-carbonate hardness as ppm $CaCO_3$	970	524	359
Total hardness as ppm $CaCO_3$	1548	878	475
Sum of constituents	1904	1148	660
Saturation index	+0.6	+1.2	+0.7

OTHER HOT SPRINGS

There are several known hot springs in the northern part of the Hughes Range, and at least two south of the Fairmont Hot Springs in the Stanford Range. The largest is in the canyon of Lussier (Sheep) River. The Lussier canyon spring issues from Beaverfoot (Upper Ordovician) strata, beside the trail on the north bank of Lussier River, at the elbow where the river passes through the Hughes Range. The water is sulphurous and emerges from two orifices. Though these are only 18 inches apart, the water temperature of one has been measured at 108° Fahrenheit, and that of the other at 62° Fahrenheit. A small cabin and two log-cribbed pools, one of which is enclosed, have been constructed at the springs.

On a northern tributary of Ram Creek, two and one-half miles from the junction of that creek with Lussier River, a spring issues from numerous closely spaced orifices in the Jubilee formation, at an altitude of 4,750 feet. The water is non-sulphurous, tastes alkaline, and deposits calcareous tufa. It is described as "comfortably warm;" the temperature is probably 90° to 100° Fahrenheit, but it has not been measured. Both the Ram Creek and Lussier canyon springs issue downslope from the traces of steeply dipping faults of east-west strike, but it is not known whether this is more than coincidence.

At a point known locally as Red Rock, on the west bank of Kootenay River, nine and one-half miles northeast of Canal Flats, there is an extensive deposit of calcareous tufa, containing abundant petrified leaves. The spring responsible for this deposit may be extinct, as no outlet is known. Two miles north of Canal Flats, on the east shore of Columbia Lake, there is a similar tufa deposit. Here also the spring source is unknown, but the water apparently issued from openings in the Jubilee formation.

BIBLIOGRAPHY

Warren, P. S. (1927): Banff Area, Alberta; Geol Surv., Canada, Memoir 153.

Satterly, M. A. and Elworthy, R. T. (1917): Radioactivity of Some Canadian Mineral Springs; Canada Dept. of Mines, Mines Br. Bull. 16, pp. 36-41.

Leech, G. B. (1954): Geology of the Canal Flats Area B..C.; Geol. Surv., Canada, Paper 54-7, Advance excerpt.

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COAL DEPOSITS
of the
SOUTHERN ROCKY MOUNTAINS OF CANADA[1]

R. T. D. WICKENDEN[2]

INTRODUCTION

This article has been prepared for the Guide Book to summarize the coal occurrences of the region and indicate where more details may be found. All information has been obtained from published sources but only where a statement is directly based on part of an author's report is a reference made to his publication.

Coal beds in the Rocky Mountain region have not only proved a great asset in the development of the west but they have played an important part in the tectonics of much of the region. The abundant supply of coal in the mountain passes was certainly of great benefit to the railways so vital to the economy of western Canada. The tectonic importance is found in the fact that many of the great thrust faults of the Rocky Mountains and Foothills have followed the Lower Cretaceous coal seams for a long distance. As Hume (1933) has pointed out, these coal seams appear to be lubricated zones along which the rock masses glided.

This brief discussion of coal deposits is confined to the occurrence found within the mountains from the Bow valley south to the International Boundary, including the area west of the almost continuous thrust masses of Palaeozoic carbonate rocks. In this region where large valleys have been eroded through the rocks overlying the major thrust faults, and between some of the thrust blocks, the coal beds of the basal Lower Cretaceous Kootenay formation have been exposed. Other formations also contain some coal in this area but, except for one or two marginal deposits, none has been developed commercially.

The Kootenay coal occurrences are localized to some extent by conditions of deposition of the sediments. The Kootenay appears to be thickest in the Fernie area. It thins gradually northward along the mountains and disappears eastward in the outer foothills. The coal seams are most numerous and thick in the region around Corbin and Fernie. Fewer seams occur in the Crowsnest, Kananaskis and Bow valleys. The thickest section of Kootenay has been reported in the Fernie area where McEvoy (1901) claims to have measured a section 4,736 feet thick. This section may have included about 1,000 feet of the underlying Fernie. The sections are much thinner in the east. Hage (1940) records 74 feet in the Alliance well in the Beaver Mines area and Beach (1943) in the Moose Mountain area, measured 220 to 350 feet. The formation is not recognized in the Plains. The thinning to the north is more gradual and in the Ribbon Creek area Crockford (1949) reports a total of 3,400 feet and the same thickness is also found in the Bow valley. The coal occurrences are located in various districts or basins usually related to some structural and stratigraphic features. The locations of these districts, namely the Flathead, Fernie (or British Columbia part of the Crowsnest), Upper Elk Valley, Crowsnest Pass (Alberta), Beaver Mines, Oldman, Highwood, and Cascade are indicated on the economic geology map accompanying this guide book (Map No. 2). The subdivisions of these districts are shown by name.

According to MacKay's (1947) estimates, the Kootenay coal basins of the mountains of all the districts discussed in this paper, contain a probable recoverable supply of coal which amounts to over eleven billion tons. Probably new methods of mining and transportation that may

[1] Published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa.
[2] Geologist, Geological Survey of Canada.

develop in the future will make available an even greater amount. Nearly all the coal is of low volatile bituminous grade with a variable ash content.

FLATHEAD DISTRICT

The Flathead district is the southernmost one, being located in southeastern British Columbia in the upper Flathead valley. The area is relatively inaccessible for commercial production and very little mining has been done. According to Mackenzie (1916), the Kootenay formation is found in an area about a mile wide and six miles long, having a northeast-southwest trend, limited on the north by Howell Creek and to the southwest by Burnham Creek. A section of 1,147 feet of Kootenay was measured here. Five coal seams are found in the lower 500 feet. The thickest coal seam is 35 feet and another seam is 25 feet.

Mackenzie indicates the structure as a down dropped part of the southeast limb of an anticline, bounded by normal or underthrust faults on the northeast, southwest, and (probably) the southeast sides. Tertiary and younger sediments in the Flathead valley cover the southeast side. It is probable that there are greater complexities but heavy forest growth covers most of the area and bedrock is exposed in few localities. This structure is shown at the southwest end of Section E-E' on page 107 of this guide book.

FERNIE DISTRICT

The coal basin indicated on the key map as the Fernie area is assigned to the Crowsnest area in most reports, regardless of the fact that most of it is outside the Crowsnest drainage, and that the major structural feature of the coal basin is separated from that of the Crowsnest Valley by a fault and an extensive mass of Palaeozoic formations. It must also be noted that the term Fernie is applied only to the mining area immediately east of Fernie in many reports. The area is somewhat pear shaped with the smaller part in the north. It extends in a north-south direction for about 35 miles and the greatest width is about 12 miles, giving about 230 square miles underlain by coal bearing formations. A total of about 3,770 feet of beds have been assigned to the Kootenay in this area by MacKay and others. Recently Newmarch (1953) revived the term Elk formation for the upper, more or less conglomeratic part of the section, restricting Kootenay to the lower, coal-bearing part of the formation. According to Newmarch, the Elk formation thins northeastward and is only 100 feet at Michel. Whether or not the Elk should be regarded as an independent formation or a member of the Kootenay may still be considered uncertain.

Up to 34 coal seams have been observed in this area, 18 of these being over 3 feet thick, but at any one locality few of there are developed commercially.

The structure appears to be a syncline or synclinorium basin. The section across the basin in the vicinity of Fernie, according to Newmarch (1953), has a gentle slope on the west, passing into a sharper fold on the east side. MacKay (1931) showed a more complex cross-section in the Michel area of a synclinorium with three minor synclines, some faulted anticlines, as well as underthrust and transverse faults. The beds at the north and south ends of the basin dip south and north respectively, indicating a canoe shape to the regional structure. At the eastern border, a fairly extensive underthrust or normal fault has been observed at some localities.

The amount of overburden and the rough terraine have limited the mining development to localities where streams have cut through the rock and exposed the coal seams where roads and approaches can be made on a suitable gradient. Several mines have been developed in the vicinity of Fernie, the most important ones being on Coal Creek. Some of these mines have had difficulties with bumps and gas. At Corbin, on the east side of the basin, a coal seam was thickened by folding to 400 feet, according to MacKay (1930). At Tent Mountain to the northwest, the same seams are exposed but have not been thickened to the same extent.

The collieries at Michel are located at the north end of the basin. This is one of the most important coal mining areas in western Canada. According to MacKay (1934), the Kootenay formation has 30 workable seams, but only few of these have been exploited. The structure is complicated by several thrust and normal faults, as well as the synclinal features of the main basin. Some of the coal is suitable for coking and during the last few years most of the coke produced in the region has come from these mines.

UPPER ELK VALLEY COAL BASIN

Farther up the Elk Valley another basin occurs which may have been part of the Fernie-Crowsnest basin at one time, but is now separated by an eroded area where a transverse structural high developed. This area is known as the Upper Elk valley coal basin. The structure is synclinal, similar to that of the Fernie (British Columbia Crowsnest area), but details of the structure have not been studied.

The Kootenay coal bearing beds are exposed in a narrow belt, about 50 miles long with a maximum width of ten miles. Erosion has taken off most of the overburden and coal is easily accessible. According to Dowling (1915), the Kootenay is about 1,800 feet thick and there are 22 seams of mineable coal. A considerable reserve of coal is available in the Upper Elk area but it would require establishing roads and a railway branch line to develop these reserves.

CROWSNEST PASS DISTRICT

The Crowsnest area in Alberta lies along the valley of the same name from the town of Crowsnest east to Burmis and, in an irregular fashion to the north and south for 6 to 18 miles or more. The Kootenay formation has a maximum thickness of 800 feet near Coleman in the west, according to MacKay (1933); in the southeast, in the Carbondale area, Clow and Crockford (1951) measured a section 280 feet thick. Farther southeast, near Beaver Mines, Hage (1940) reports that the Alliance well passed through only 74 feet of Kootenay.

The number of coal seams is fewer and they occur closer to the top of the formation than they do in the Fernie area. MacKay (1933) reports five seams with only three workable seams. In the Carbondale area, Clow and Crockford (1951) show the presence of nine coal seams, five of which have a thickness of over 3 feet. Some of the other sections in the area have no important seams. In some localities, the thinning, or apparent disappearance of the coal, may be due to thrust faults and other structural features which forced the strata to move along the coal seams as gliding planes.

Near Sentinel, in this area, is an occurrence of coal in the Upper Cretaceous Belly River formation. This is a small deposit but it is interesting to note that the coal is of much the same grade as that in the Lower Cretaceous, according to MacKay. This indicates that structural movements have more to do with the grade of coal in the area than the age of the formation in which the seams occur.

The structure in the Alberta Crowsnest area is fairly complex. The cross-section published by MacKay (1933) shows an eroded anticline with faulted synclines and possibly minor anticlines to the east and west. These features are bounded on the east and west by major thrust faults which bring beds of Palaeozoic age against Upper Cretaceous sediments.

OLDMAN RIVER AREA

Along strike north of the Crowsnest area, in the Oldman and Livingstone valley, is another area where the Kootenay formation is exposed in several bands or thrust blocks. Prospecting has not been extensive and the coal deposits have not been developed, although the area has considerable reserves.

The Kootenay in this area may have a thickness of 700 feet in the western part and 370 feet in the eastern part. The coal seams appear to be similar to those in the Crowsnest district. Douglas mentions one about 9 feet thick near the top of the Kootenay, and another about 3 feet thick lower in the section.

The structure in the Oldman area is complicated and has been studied in detail in the Gap area by Douglas (1951). Rocks of Palaeozoic age are brought to the surface in the eastern part in an anticlinal thrust fault structure along the Livingstone Range. The Kootenay is found as a belt on the sides of this structure. To the west the Kootenay is brought to the surface again at several localities by thrust faults, and folds. Rose (1919), in his discussion of the area, mentioned that the Kootenay was repeated ten times in a cross-section 9 miles long.

HIGHWOOD RIVER AREA

Although a few bands of Kootenay continue north from the Oldman area along the mountain, the valley of the Highwood River is the next locality where good prospects have been developed to some extent. Carr and Allan (1947) found that the Kootenay varies from 2,400 feet in the west to 700 feet in the east, in this area. The formation in the southeastern part resembles the Kootenay of the Fernie district in that the top is a series of sandstones with some conglomerate beds, and the lower part has sandstones and shales with coal. In the northwestern sector, the coal is distributed throughout the section. Five seams of commercial thickness have been observed in the area. The thickest seam is 26 feet. Folding and faulting has thickened some seams.

The structure affecting the Kootenay formation at the surface is a series of three faults which originated on the west limbs of synclines, west of the major thrust block of the Highwood Range where Palaeozoic strata are exposed. To the west the area is limited by another major thrust fault where the Palaeozoic formations are exposed on the Elk Mountains.

CASCADE DISTRICT

The northernmost coal district discussed in this paper has been called the Cascade, probably because of its proximity to Cascade mountain north of Bow valley. The coal occurrences are along the valleys of the Bow and Kananaskis Rivers. This district is the farthest north within which Kootenay coal deposits have been developed, although these strata have what appears to be commercial coal about 30 miles north of Bow valley in the Panther valley. The Cascade occurrences are developed in two principal localities, Canmore in Bow valley, and Ribbon Creek, a tributary of the Kananaskis. Some other mines have been developed as far west as Banff in the Bow valley but all have closed or been abandoned.

The occurrence is along a belt one to three miles wide and about 60 miles long. The thickness of the Kootenay formation varies from 3,100 to 3,400 feet according to Crockford (1949). The same author considers that there are four lithologic members; a sandstone 40 to 70 feet thick at the base, succeeded by a shale and coal bearing unit 1,150 feet thick, overlain by another sandstone members 1,839 feet thick, and a conglomeratic member 340 feet thick at the top. The section in the Bow valley may be a little thinner.

As many as 23 seams of coal were reported by Dowling (1909) although most of the seams are not thick enough or of sufficiently good quality to warrant mining. Crockford (1949) reports 14 seams, 7 of which are 3 feet or over. One seam is 24 feet thick and, at another locality, merges into a total thickness of 34 feet of coal including some shale partings. The distribution and thickness of the coal seams varies from locality to locality in the Cascade district. The best seams are found in the lower part of the shale and coal bearing unit in the Ribbon Creek sector,

whereas, according to MacKay (1935), the lowest seams are 450 to 700 feet above the base of the Kootenay in the Canmore area.

The structure involving the Kootenay formation in the Cascade coal basin is that of an asymmetrical syncline, according to Crockford (1949). A major thrust fault cuts the west limb of the syncline, and some minor thrust faults occur within it.

About 30 miles north of the Bow valley, in Panther River valley, a prospective coal field in the Kootenay formation has been reported. This is as far north as the Kootenay coal measures have been traced, although an equivalent formation may contain coal in areas farther north, but the correlations have not been established.

REFERENCES

Allan, J. A. and Carr, J. L. (1947): Geology of the Highwood-Elbow Area, Alberta; Research Council of Alberta, Rept. 49.

Beach, H. H. (1943): Moose Mountain and Morley Map-Areas, Alberta; Geol. Surv., Canada, Mem. 236.

Clow, W. H. A. and Crockford, M. B. B. (1951): Geology of Carbondale River Area, Alberta; Research Council of Alberta, Rept. 59.

Crockford, M. B. B. (1949): Geology of Ribbon Creek Area, Alberta; Research Council of Alberta, Rept. 52.

Dowling, D. B. (1909): Steam Coals of the Cascade Basin; Geol. Surv., Canada, Sum. Rept. 1908, pp. 77-80.

1915): Coal Fields of British Columbia; Geol. Surv., Canada, Mem. 69.

Douglas, R. J. W. (1951): Callum Creek, Langford Creek and Gap Map-Areas, Alberta; Geol. Surv., Canada, Mem. 255.

Hage, C. O. (1940): Beaver Mines, Map No. 739A; Geol. Surv., Canada.

Hume, G. S. (1938): Waterton Lakes-Flathead Area, Alberta and British Columbia; Geol. Surv., Canada, Sum. Rept. 1932, Pt. B, pp. 1-20.

MacKay, B. R. (1931): Corbin Coal Field, British Columbia; Geol. Surv., Canada, Sum. Rept. 1930, Pt. A, pp. 161-163.

(1933): Geology and Coal Deposits of Crowsnest Pass Area, Alberta; Geol. Surv., Canada, Sum. Rept. 1932, Pt. B, pp. 21-67.

(1934): Michel Coal Area, British Columbia, and Coleman South Coal Area, Alberta; Geol. Surv., Canada, Sum. Rept. 1933, Pt. B, pp. 1-19.

: Canmore Area, Alberta; Geol. Surv., Canada, Maps 322A, 323A and Cross-sections.

(1947): Coal Reserves of Canada; Reprint of Chapter 1 and Appendix A of Report of the Royal Commission on Coal 1946.

MacKenzie, J. D. (1916): Geology of a Portion of the Flathead Coal Area, British Columbia; Geol. Surv., Canada, Mem. 87.

McEvoy, J. (1901): Geol. Surv., Canada, Ann. Rept. 1900, pp. 85A-95A.

Newmarch, C. B. (1953): Geology of the Crowsnest Coal Basin with Special Reference to the Fernie Area; British Columbia Dept. of Mines, Bull. No. 33.

Rose, B. (1919): Northern Part of Crowsnest Coal Field, Alberta; Geol. Surv., Canada, Sum. Rept. 1918, Pt. C, pp. 13-16.

FIELD TRIP GUIDE

LIST OF MAPS PERTINENT TO THE AREA[1]

MOST USEFUL MAPS

I. *Topographic Maps*

Banff and Vicinity: 1 mile to 1 inch, 1926, Topographical Survey of Canada, Ottawa (25 cents).

Banff Park : 3 miles to 1 inch, 1946, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa, (15 cents).

Yoho Park : Sheet No. 82 N/SE, 2 miles to 1 inch, 1952, Dept. Mines and Tech Surv., Surv. and Map Branch, Ottawa, (25 cents).

Kootenay Park : 2 miles to 1 inch, 1938, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa, (25 cents).

Lake Louise : 2 miles to 1 inch, 1948, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa, (25 cents).

Revelstoke-Golden: Map 5D, 4 miles to 1 inch. Obtainable at B.C. Dept. of Lands, Victoria, B.C. (50 cents).

National Topographic Series:

Banff-Bassano : 8 miles to 1 inch, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa, (25 cents).

Vernon-Golden: 8 miles to 1 inch, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa, (25 cents).

II. *Geological Maps*

Transcontinental Excursion Guide Book No. 8, Part II, 1913, Geol. Surv., Canada, (25 cents). (Complete Guide Book, 75 cents).

Field Map-Area B.C.. by J. A. Allan, 1914, Geol. Surv., Canada, included in Memoir No. 55 (75 cents).

Lardeau Area, Kootenay district, Geology, Map No. 235A, 4 miles to 1 inch, Geol. Surv., Canada, (25 cents).

Geological map of B.C., Map No. 932A, 20 miles to 1 inch, 1948, Geol. Surv., Canada, (50 cents).

Geological map of Alberta, Map No. 1002A, 20 miles to 1 inch, 1951, Geol. Surv., Canada, (50 cents).

Mineral Map of B.C., Map No. 1008A, 1952, 20 miles to 1 inch, Geol. Surv., Canada, (50 cents).

Stanford Range, G. G. L. Henderson, accompanying B.C. Dept. Mines Bulletin 35 (in press).

[1] Compiled by E. Atkinson, Hudson's Bay Oil and Gas Company Limited, Calgary, Alta.

OTHER MAPS

I. *Topographic Maps*

* Calgary Sectional Sheet, No. 114, 3 miles to 1 inch, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa.

* Banff Sectional Sheet, No. 164, 3 miles to 1 inch, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa.

Kootenay River, World Aeronautical Chart, 1:1,000,000, 1948, Map No. 2216, Dept. Mines and Tech. Surv., Surv. and Map Branch, Ottawa (25 cents).

II. *Geological Maps*

* Banff Area, Alberta, P. S. Warren, 1927, Geol. Surv., Canada, included in G.S.C. Memoir 153.

* Guide Book, A.A.P.G. Convention, at Banff, 1950 (map included).

* Brisco-Dogtooth Map-Area, by C. S. Evans, 1932, Geol. Surv., Canada, included in G.S.C. Summary Report, Pt. A, II.

* Windermere-Kootenay District, Geology, Map No. 2070, Geol. Surv., Canada, 2 miles to 1 inch.

* Windermere Map-Area, B.C., J. F. Walker, 1926, Geol. Surv., Canada, included in G.S.C. Memoir No. 148.

* Calgary Area, Geology, Map. No. 204A, Geol. Surv., Canada, 8 miles to 1 inch, 1928.

* Geology of the Railway Belt between Golden and Revelstoke, 10 miles to 1 inch, R. A. Daly, 1915, Geol. Surv., Canada, Memoir No. 68.

Notes

1. Geological Survey of Canada Summary Reports and Memoirs may be obtained from the G.S.C. office in Calgary in the Customs Building, 11th Avenue and 1st Street E., or from the Dept. of Mines and Technical Surveys, Ottawa.

2. Maps are obtainable from the Map Distribution Office, Dept. of Mines and Technical Surveys, Ottawa.

4. Topographic maps of Alberta are available from T. W. Dalkin, Director Technical Division, Dept. of Lands and Forests, Edmonton.

5. Available topographic maps of the National Parks may be obtained at the Information Bureau in Banff, or at the Information office at Radium Hot Springs.

* Out of print.

ROAD LOG[1]

PART I - BANFF TO GOLDEN

Mile	
	From start to point 19.3, route crosses third and fourth ranges of Front Ranges sub-province.
00.0	Banff railway crossing
01.5	Third range, with Sulphur Mountain on left and Mount Norquay on right. Essentially same upper Palaeozoic succession as in first and second ranges (Plate 5).
02.0	Palliser, Banff and Rundle formations visible on Mount Norquay on right.
03.7	Within fourth range; red-weathering shaly beds on right are in Upper Cambrian Arctomys formation, oldest beds exposed in Sawback Range at this latitude.
04.2	Mount Edith visible through gap to right; minor fault-slice, preserving narrow band of east limb of anticline in almost vertical Palliser limestone.
04.7	"Rocky Mountain Sheep Range" sign pointing to main rib of Sawback Range on right, formed of thickly-bedded Ottertail limestone (Upper Cambrian) with steep westerly dip.
05.5	"Rocky Mountain Goat Range" sign pointing to typical McKay (Goodsir) limestones in Sawback Range succession on right.
05.7	Fairholme on right, nearly vertical; note algal vugs in road-cut outcrop.
06.2	Overlying Palliser limestone on right, nearly vertical, forming greater part of west face of Sawback Range.
06.4	Pilot Mountain ahead to left; upper cliffs in Rundle formation, nearly flat-lying.
06.8	First view of Mount Eisenhower ahead; front of Main Range.
07.2	Upstanding Rundle limestone in spike of Sawback Range, ahead to right.
07.9 to 09.3	Good views of west face of Sawback Range, composed of steeply dipping Palliser and Rundle limestones, with brown weathering Banff shales eroded into gulley between.
10.2	View of Castle Mountain syncline ahead; Stuart Knob in centre, composed of limestone of basal Upper Cambrian; Helena Ridge on right, with same Middle Cambrian section as in Mount Eisenhower. Ridge underlain by Castle Mountain thrust, which defines eastern boundary of Main Ranges sub-province. There are glacial erratics on Mount Eisenhower to elevation of 8,300 feet or higher.
11.6	Tree in road; trail on left into valley of Redearth Creek; route to Pilot Mountain and Mount Ball.
12.6	Mount Ball, in Main Range, visible through gap to left; Spray River shales exposed in road cuts to right, in axis of syncline between west face of Sawback Range and Pilot Mountain block.
14.1	Last outcrop of Spray River formation; fine view of Mount Eisenhower ahead.
15.3	Johnston Canyon; Pilot Mountain on left; two limestone cliffs formed of Rundle and Palliser formations.

[1] Compiled by F. K. North and G. G. L. Henderson.

18.5 First full view of Bow Range, including Storm Mountain to south, Mount Whymper and Boom Mountain to right of Vermilion Pass, and Mount Temple to north.

19.3 Castle Mountain Junction: STOP.

Points to discuss:

(1) Castle Mountain thrust; relation to Mount Eisenhower and Copper Mountain; Castle Mountain syncline.
(2) West face of Sawback Range to east; relation to thrust.
(3) Bow River anticline; Mount Eisenhower on east limb, Bow Range on west limb.
(4) Stratigraphy on Mount Eisenhower and Storm Mountain; Eldon on top, Cathedral in middle cliffs, St. Piran below.
(5) Stratigraphy in Bow Range; typically Cathedral above, St. Piran below.
(6) Distribution of Precambrian.

From this point to 55.0, route lies within eastern sector of Main Ranges sub-province; as far as 37.0, route follows strike along approximate axis of Bow River anticline, wholly underlain by Precambrian sediments.

20.8 Good view of Mount Whymper on left, to southwest of Bow Range. Peak in Eldon dolomite; central cliff in Cathedral dolomite, base in Lower Cambrian quartzite.

26.9 Eldon station on left; gave name to great Middle Cambrian formation capping Mount Eisenhower. From this point and for some distance ahead, view of Mount Daly ahead: cliffs of Middle Cambrian dolomites, on Continental Divide north of Mount Bosworth. From Daly Glacier, on west flank of mountain, Takakkaw Falls descend.

29.1 Baker Creek; drains west flank of Sawback Range. Good view of Mount Temple half left; basal Eldon on peak, Stephen, Cathedral, and Mount Whyte formations forming upper half of mountain, St. Piran quartzite lower half, Precambrian at base.

31.4 Mount Tuzo and Deltaform Mountain visible to left at west end of Valley of Ten Peaks; cliffs of Lower and Middle Cambrian.

32.0 View of some of Ten Peaks to left, with stratigraphy as on Deltaform Mountain.

34.4 View of Mount Hector ahead; highest peak east of Bow Valley and south of Saskatchewan crossing; Middle Cambrian dolomite forming peak; dipping east on east limb of Bow River anticline

34.5 Corral Creek; type-locality of Precambrian sandstone formation up creek to northeast, poorly exposed; first view of Mount Bosworth ahead.

35.0 Outcrops of Precambrian Hector formation on left; greenish argillite and shale with bands of conglomerate; nearly flat-lying, about on axis of Bow River anticline.

35.5 East end of Mount Bosworth visible ahead.

35.8 Railway crossing; fine views of north end of Bow Range; note permanent glaciers.

37.0 Main road junction; highway turns west and crosses Main Range.

37.1 Bridge over Bow River.

38.4 Road to Moraine Lake, which lies at head of Valley of Ten Peaks; lake actually dammed, not by moraine, but by landslide from Tower of Babel.

39.1 Chateau Lake Louise turnoff; mountain on left is Mount Fairview (Plate 6), name originally given by Walcott to Lower Cambrian quartzites well exposed in greater part of mountain.

42.0 Good view of Mount Bosworth straight ahead.

43.6 On right, melt water channel of late glacial and immediate post-glacial period; water drained eastward into Bow River.

43.7 Great Divide (Kicking Horse Pass); Slate Mountains to east, on east limb of Bow River anticline; Waputik Range along strike to north, Bow Range to south, with Mount St. Piran the nearest mountain. Except on Mount Bosworth and mountains farther west, only formations immediately visible are Cathedral, Mount Whyte, and St. Piran. Divide is entrance to Yoho Park.

44.1 Railway crossing (blind).

44.7 Sink Lake, with no outlet and presumably a kettle; Mount Bosworth on right.

45.1 Mount Bosworth: POSSIBLE STOP.

Points to note:

(1) Redoubt Mountain, on east limb of anticline, capped by thin Stephen limestone; thick dark band is Cathedral formation.
(2) Bow and Waputik Ranges, on west limb of anticline.
(3) Walcott's type Cambrian section on Mount Bosworth.
(4) Mounts Field and Cathedral to west.
(5) General westerly dip, assisted by normal faults originally downthrown to west.

45.5 Mount Odaray visible through gap half left; on strike with Mount Stephen and capped by basal Stephen formation and Cathedral dolomite, dipping west.

46.1 Railway crossing; outcrop of Cathedral formation dipping west. Approaching fault line; fault almost vertical, and originally of normal downthrow to west. Steep inward dip of beds on two sides suggests, however, that there must have been reversed movement along fault plane since original normal movement.

46.4 Kame moraine on left, forming straight ridge along valley side.

46.7 Wapta Lake on left; Cataract Brook entering from south, following approximate line of vertical fault.

48.0 Sherbrooke Creek; transitional contact between Eldon and Stephen immediately west of bridge, dipping steeply to east in west wall of vertical fault. Note cleavage in Stephen formation. From this point to 50.0, route crosses progressively older beds in road-cut outcrops.

48.2 Small reef-like lens in Cathedral formation (Plate 19); vuggy, recrystallized, pale dolomite, with sharp contacts with typical gray dolomite and limestone. Lens contains apparent algal growths, especially near lower (western) contact.

48.5 Bridge over Kicking Horse River.

48.6 Mount Whyte formation on left; more thinly bedded than formations above or below, with abundant greenish shale. Contains *Olenellus* fauna in limestone bands near base.

48.8 Bridge, Yoho Valley on right; about contact with St. Piran quartzite. Upper part of quartzite contains thin interleaves of greenish argillite, highly cleaved.

49.5 Rusty-weathering quartzite on both sides of road.

49.7 Railway crossing; fine view of Mounts Field and Wapta ahead. First view, to left, of Van Horne Range; note very different topography, due to erosion of dipping Chancellor beds.

50.0 Huge vertical joint surface in Eldon formation on upper east face of Mount Stephen. Cathedral-Stephen fault lies very close to this face, and is nearly vertical, with 3,000 feet downthrow to west.

50.5 Mine buildings of Monarch mine ahead; portal of Monarch mine in mountain face near base of steep cliff, which is composed of dolomitized limestone of Cathedral formation; thinly bedded Mount Whyte formation below portal.

51.0 Railway crossing.

51.6 Bridge over Kicking Horse River and junction with road to Yoho Valley; Yoho River is real headwater of Kicking Horse drainage system.

52.0 Kicking Horse River flat: LUNCH STOP.

Points to note:

(1) Cathedral Crags, top in Eldon dolomite.
(2) Mounts Stephen, Ogden, and Field, largely in Middle Cambrian formations.
(3) Van Horne Range, largely in beds of Chancellor (argillaceous) facies.
(4) Cathedral-Stephen fault between mountains of those names; normal downthrow to west of about 3000 feet.
(5) Stratigraphy with respect to mine entrances.
(6) Nature of mines; selective dolomitization in basal Cathedral formation on Mount Field.
(7) Burgess shale, on west face of Mount Wapta, north of Mount Field.

55.0 Junction leading to Field: STOP if time permits.

Points to note at Field:

(1) Walcott's work on Mount Stephen.
(2) Fossil beds.
(3) Stephen-Dennis fault, relation to Mounts Stephen, Dennis, and Burgess.
(4) Valley of Kicking Horse; glaciation of Mount Stephen.
(5) First appearance of Chancellor group; facies change.

From this point to 72.0, route crosses western sector of Main Ranges sub-province.

55.5 Outcrops of Eldon formation on right, on west slope of Mount Burgess, in carbonate facies.

56.2 to 56.6 Outcrops of reddish-weathering Chancellor formation; all road level outcrops from this point to mile 70 are of sheared Chancellor.

56.9 Emerald Lake road junction.

57.7 Natural bridge: STOP if time permits; minor contortions in Chancellor beds of dominantly low dip; prominent cleavage nearly vertical (Plate 14).

58.7 Bridge over Kicking Horse River at entry of Amiskwi and Emerald Rivers. Outcrops sheared Chancellor in river on both sides; cleavage attitude 130/80° SW; bedding obscure, apparently gently folded as at Natural Bridge, dominant dip 0-35° SW.

59.2 Chancellor on left; bedding attitude 310/60° SW; major cleavage dips 80° SW.

59.3 Looking along strike of "Rock Wall" ahead; first view of main rib of Ottertail limestone in Ottertail, Vermilion, and Mitchell Ranges; prominent sharp peak is Mount Ennis.

60.0 Boulder Creek, heading on west side of amphitheatre behind Mount Stephen.

61.5 Dempster Creek (Haygarth Creek of most maps); high ridge of Chancellor shales ahead, with Ottertail limestone of "Rock Wall" above.

62.0 Probable approximate position of Ottertail River fault, a westerly-dipping thrust fault necessarily inferred between Ottertail Range and Stephen-Dennis fault.

62.2 Bridge over Ottertail River; immediately west of bridge (to right), river turns due south and flows for two miles parallel to Kicking Horse River before joining it.

62.7 Railway crossing; prominent pyramidal peak directly behind is Mount Carnarvon, composed largely of Middle Cambrian limestones; President Range to right of peak and beyond (on strike with Mount Stephen).

63.3 Sheared Chancellor on left; bedding dips approximately 45° SW; attitude main cleavage 315/60° SW.

63.6 to 68.5 Outcrops of sheared and phyllitic Chancellor, mostly on left of road; typically at least two directions of cleavage, but bedding in all cases dips east and cleavage dips more steeply than bedding; this stretch therefore on east (upper) limb of anticline; detail follows.

63.6 Bedding attitude approximately 250/2-5° SE; main cleavage dips 25° S. On east face of Van Horne Range across river, note typical timbered slopes and reddish weathering of Chancellor group.

63.8 to 64.1 Bedding essentially horizontal, with slight east component to dip; two main cleavages with variable attitude, one vertical and striking nearly east-west, another less regular and dipping about 30° SE.

64.3 Main cleavage about 300/40° S; second cleavage about 240/65° E but less regular; bedding nearly horizontal with slight southeast component.

65.0 Bedding steepens to 260/27° SE; prominent crinkly cleavage 225/75° SE; beds much more massive (hard dense grey limestone), with several prominent joint-planes.

65.1 Bedding returns to nearly horizontal, with slight east component; prominent cleavage 315/40° SW.

66.9 Excellent exposure of sheared Chancellor on left (Plate 20); increasingly massive appearance, prominent jointing; gentle southeasterly dip, steepening to south; main cleavage 327/75° SW.

67.7 Chancellor consists of hard, thinly bedded limestone with lustre mottling on cleavage surfaces; bedding attitude 330/60° NE; several directions very steep cleavage, including one vertical. Good view behind of Mount Hurd, northernmost peak in Ottertail Range; capped by basal Goodsir (not visible from road), rest of peak in Ottertail limestone; lower tree-covered slopes in Chancellor, of which excellent section seen in cutbank (grey-brown, well bedded, gentle east dip).

67.9 Bedding essentially horizontal, slightly undulatory; main cleavage dips 80° NE. Top of Chancellor group in Van Horne Range (across river) distinctly red here.

68.2 to 68.5 Bedding gradually flattens from 40° NE to 25° NE, striking due northwest; main jointing dips 80° NE. Rather massive limestone, with faint bedding which has been

PLATE 20

Cleaved limestone of Chancellor group on east side of Kicking Horse Valley, southwest of Field. Faint bedding dips gently southeast (to right and into paper). Four very prominent cleavages, all dipping more steeply than the bedding, give massive, jointed effect. Photograph by M. K. Sorensen.

PLATE 21

Pulverized McKay of the White River Break. Kicking Horse Canyon section, near Palliser. Note zones of mylonite surrounding relict blocks of unsheared limestone. Photograph by M. K. Sorensen.

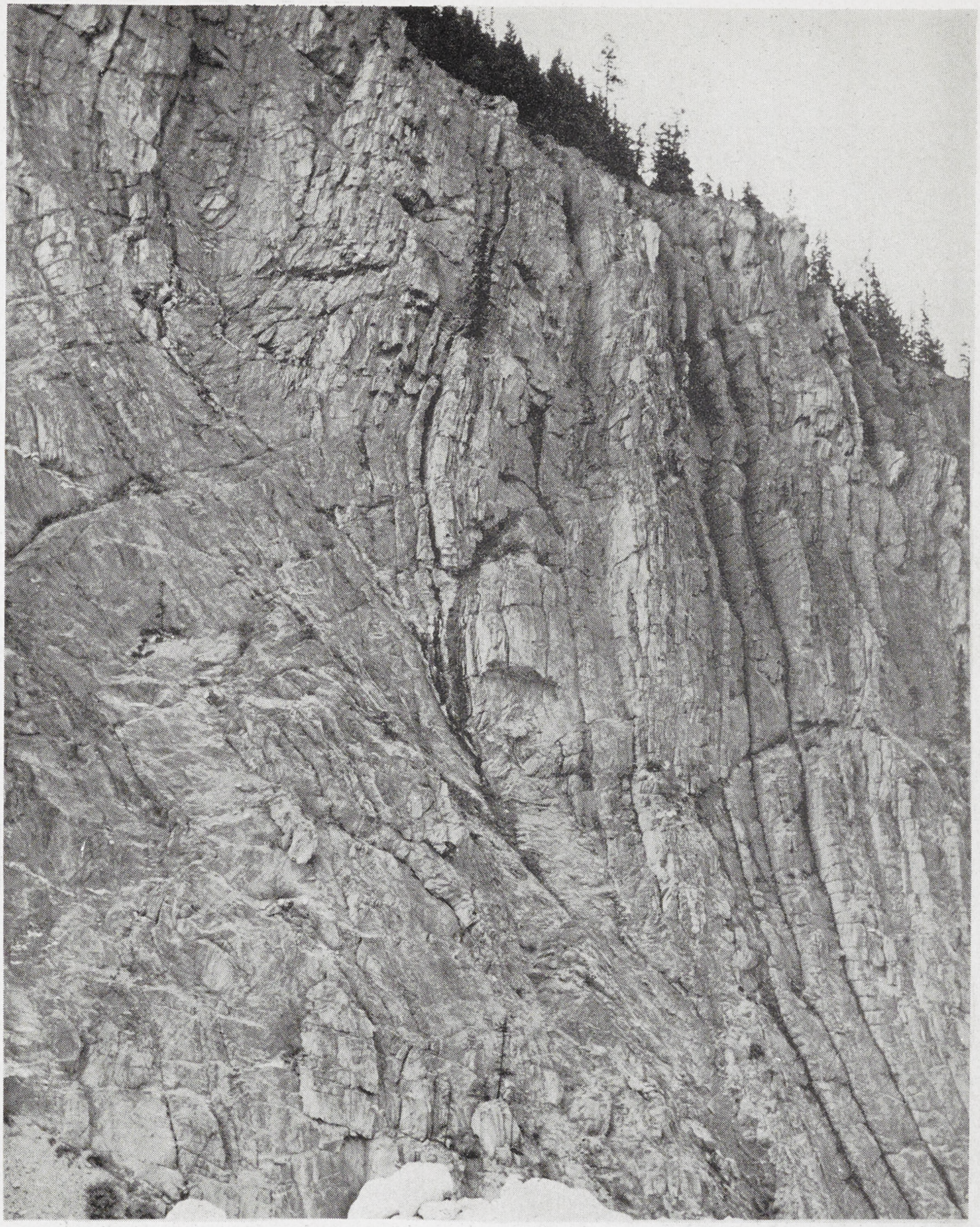


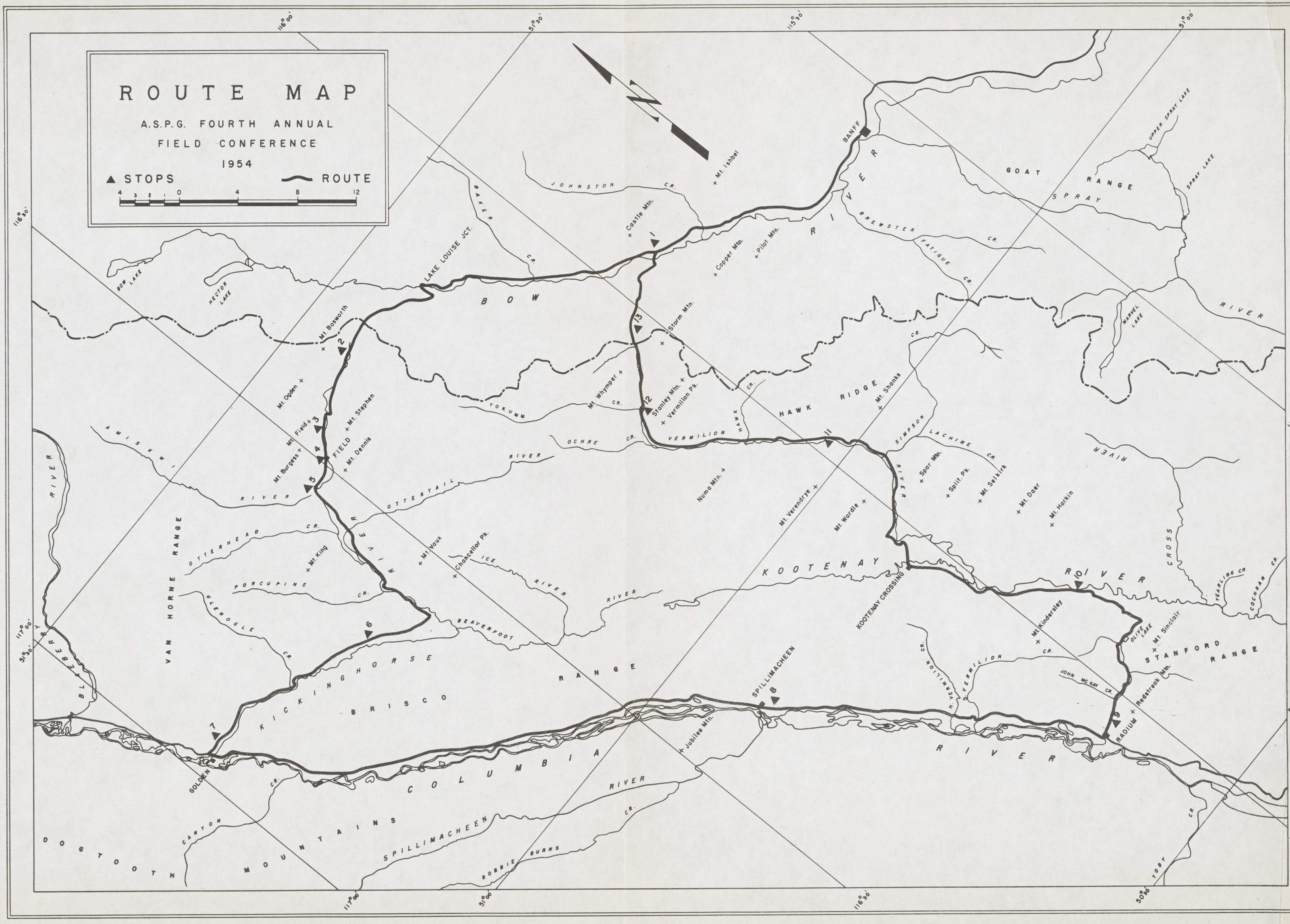
PLATE 22

Typical well-bedded limestones of the unsheared McKay. Kicking Horse Canyon section, east of Glenogle. The beds are almost vertical, and are cut by several reverse faults with steep easterly dip.

Photograph by M. K. Sorensen.

PLATE 23

Detail of flat thrust fault exposed on north side of highway four miles east of Golden. Contorted black shales in hanging wall are overturned towards the east (right). McKay limestones in footwall appear undisturbed, but are on upper limb of an anticline overturned towards the west (left). Photograph by M. K. Sorensen.


ROUTE MAP
A.S.P.G. FOURTH ANNUAL
FIELD CONFERENCE
1954
STOPS
ROUTE
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N
BANFF
LAKE LOUISE JCT.
GOLDEN
FIELD
RADIUM
KOOTENAY CROSSING
SPILLIMACHEEN
BOW RIVER
BOW LAKE
HECTOR LAKE
BAKER CR.
JOHNSTON CR.
BREWSTER CR.
FATIGUE CR.
GOAT RANGE
SPRAY
UPPER SPRAY LAKE
SPRAY LAKE
MARVEL LAKE
RIVER
+ Castle Mtn.
+ Mt. Ishbel
+ Copper Mtn.
+ Pilot Mtn.
+ Storm Mtn.
+ Mt. Bosworth
Mt. Ogden +
Mt. Whymper +
Stanley Mtn. +
+ Vermilion Pk.
+ Mt. Shanks
HAWK RIDGE
HAWK CR.
TOKUMM CR.
VERMILION RIVER
OCHRE CR.
SIMPSON RIVER
LACHINE CR.
CROSS RIVER
Mt. Field +
+ Mt. Stephen
Mt. Burgess +
+ Mt. Dennis
AMISKWI RIVER
OTTERTAIL RIVER
Numa Mtn. +
Mt. Verendrye +
Mt. Wardle +
+ Spar Mtn.
+ Split Pk.
+ Mt. Selkirk
+ Mt. Daer
+ Mt. Harkin
VAN HORNE RANGE
OTTERHEAD CR.
+ Mt. King
PORCUPINE CR.
GLENOGLE CR.
KICKING HORSE RIVER
+ Mt. Vaux
+ Chancellor Pk.
ICE RIVER
BEAVERFOOT RANGE
KOOTENAY RIVER
YEARLING CR.
COCHRAN CR.
+ Mt. Kindersley
+ Mt. Sinclair
OLIVE LAKE
STANFORD RANGE
+ Redstreak Mtn.
VERMILION CR.
N. VERMILION CR.
JOHN MC KAY CR.
BLAEBERRY RIVER
BRISCO
+ Jubilee Mtn.
COLUMBIA RIVER
CANYON CR.
SPILLIMACHEEN RIVER
BOBBIE BURNS CR.
DOGTOOTH MOUNTAINS
TOBY CR.
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rendered discontinuous by boudinage-effect due to deformation.

68.7 Bedding steepens abruptly to 300/80° NE, and becomes steeper than main cleavage, which dips about 70° NE; presumably sharp but minor drag-fold.

68.8 First appearance of westerly dip since 63.3; bedding attitude 310/68° SW with minor contortions; note claystone "dykes," derived by squeezing out of material from clayey bands during deformation.

69.1 Bedding dips steeply to southwest; cleavage steeper than bedding, nearly vertical to overturned towards west (i.e. apparent steep easterly dip).

69.4 Good view along east face of Brisco Range, showing dominant steep dips in Ordovician strata.

69.6 Bedding returns to easterly dip (315/30-45° NE); main cleavage 315/75° NE. Chancellor Peak high up on left; west face consists of irregularly westerly dipping Ottertail limestone, with Chancellor beds below; hence some minor folding between river and base of Ottertail Range.

70.7 Bridge over Kicking Horse River; prominent peak to north is Mount King, on east face of Van Horne Range; composed of red brown beds of Chancellor group.

71.0 Bridge, back channel.

71.1 Railway-cut outcrops on west side of river, immediately across bridge, apparently of Chancellor. Abrupt reduction in degree of shearing (about like that at Natural Bridge). Cleavage (dip 30° east) flatter than bedding (dip 60° east); presumed overturned limb of fold, which is therefore overturned towards *west.* Fine view eastward of Mount Vaux and Chancellor Peak; gap between peaks is valley of Hoodoo Creek, with well developed hoodoos and perched blocks near mouth (not visible from road). Hanbury Glacier, northernmost glacier in Ottertail Range, above head of creek valley.

71.6 Last outcrop of Chancellor.

72.4 Wapta bend; outcrop on right of sheared Ottertail limestone overturned towards west. Valley of Beaverfoot River to left. Immediately around bend, irregular cleavage dips 30° east approximately, bedding dips 75° northeast, in shear-zone of White River Break. Rocks presumably of lower part of Goodsir group, overturned towards west.

From this point to Golden, route crosses Western Ranges sub-province.

73.3 Fine view backwards, and to right, of Mount Vaux and Chancellor Peak, on west face of Ottertail Range.

73.7 Railway crossing, old road.

74.2 to 81.4 All road-level outcrops are of sheared, pulverized McKay in zone of White River Break. McKay is name used in Western Ranges for beds included within Goodsir group of Ottertail Range.

75.8 Passing along strike northwestward. On right, west face of Van Horne Range (Mount Hunter), showing tight isoclinal anticline in Ottertail limestone, overturned towards west. Chancellor fault lies east of this overturned fold, and dips east. On left, east face of north end of Brisco Range, largely in tightly folded Ordovician rocks.

78.0	STOP. Points to discuss: (1) Valley of Kicking Horse River, and its southerly continuation up Beaverfoot River; forms west boundary of Yoho Park; lacustrine silts. (2) Brisco Range on west; structure and stratigraphy. (3) Van Horne Range on east; structure and stratigraphy. (4) Outcrop of sheared, phyllitic McKay; White River Break. (5) Remarks on thrust-wedge and origin of shearing.
80.1	New bridge over canyon cut in sheared McKay of White River Break.
82.1	Sheared McKay on right includes some lenses or relict blocks of massive, blue-grey limestone (Plate 21).
82.3 to 83.2	Cliffs of highly contorted McKay on right, on upright (east) limb of anticline.
83.6	Bridge, dangerous bends. Uppermost McKay sharply overturned into anticline. Vertical beds to right of bridge (Plate 22) are in west limb, broken by minor faulting. Note great proportion of greyish limestones in uppermost McKay, and absence of shearing.
83.9	Transitional contact between McKay group and overlying Glenogle formation.
84.1	Black shales of Glenogle formation exposed in river bed to right. McKay forms cliffs on east bank, overturned towards west.
84.3	Glenogle Creek entering river from north (right). Moberly Peak straight ahead; on geological basis, this is northernmost peak in Brisco Range; geographically it is included in Van Horne Range.
84.4	Wonah quartzite caps low ridge to left of road; road paved with Glenogle shale.
84.9 to 85.1	Outcrops of Glenogle shale on left of road; graptolites not plentiful here. Glenogle Station across river to right.
85.4	Contact between Glenogle shale and overlying Wonah quartzite; latter exposed on left of road, on east limb of syncline overturned towards west.
85.8	Corner in road. Contact between Wonah and Beaverfoot formations; outcrops visible east of river.
85.9	Outcrop of Beaverfoot dolomite on left of road; also forms lower half of cliffs east of river, these outcrops being on strike with overturned syncline on Moberly Peak, seen from Golden. Note tripartite form of Kicking Horse Valley: glacially modified down to about 4000 feet elevation; V-shaped from 4000 to 3200 feet; present canyon below 3200 feet.
86.4	Across river on right, contorted zone in Beaverfoot-Brisco, lying on opposite side of nearly vertical fault.
86.7	Wooden bridge, dangerous bends. Breccia-zone of fault crosses road at north end of bridge; immediately around bend, road runs about on and parallel to fault. Up slope on right, Beaverfoot-Brisco; cliffs high up on left are of Wonah quartzite.
86.8	Big rock at road level is boulder of typical Beaverfoot-Brisco dolomitic limestone.
87.1	On west side of river, dip-slope of Glenogle shale exposed beneath Wonah on hillside; displaced by small transverse fault and again exposed in dip-slope at river level. Hillside exposures cut off at top by westerly-dipping longitudinal fault. Contorted

uppermost McKay above fault, giving appearance of being massive, caps rounded hilltop and underlies most of timbered hillsides. From this point to 88.6, road in general follows base of Wonah quartzite, in west wall of major longitudinal fault.

87.8 Lower Kicking Horse canyon below on left, cut largely in shales and limestones of McKay group. Dogtooth Mountains visible through gap to left, on opposite side of Rocky Mountain Trench.

88.6 High ridge ahead exposes westwardly-overturned drag anticline in massive Beaverfoot-Brisco, cut off on west by fault, approximately vertical to steep dip to east. On west side of fault, Wonah quartzite dips very gently to east, with thin Glenogle below and then McKay down to bottom of canyon. At sharp left turn, topmost sandy part of Glenogle is exposed on right of road.

88.8 In road cut on right, small tight syncline in cleaved McKay, overturned towards west.

89.2 On right of road, sheared black shale, presumably Glenogle, highly drag folded and metamorphosed in hanging wall of flat thrust. Drags indicate movement towards *east*.

89.4 STOP if possible:
Exposure of fault, which at this point dips gently to *east* and is therefore presumed to be folded. Thrusts contorted Glenogle over McKay, which dips 30° northeast in footwall. Cleavage indicates that footwall McKay is on east limb of a westwardly-overturned anticline (Plate 23); exposures between this point and 90.4 confirm this structure.

89.5 Deposit of buff-coloured tufa on right; no spring visible.

89.7 On right and in cliffs ahead, McKay limestone with interbeds of calcareous shale. Whole canyon cut in McKay; dip 20-30° northeast, with upright drags. Note that present canyon cut below older V-shaped valley nearly 1000 feet deep.

89.9 Prominent bluff across river is in McKay limestones; may be an upright drag-fold, but more probably nose of major anticline overturned towards west.

90.4 Drag folded McKay exposed on right of road and in canyon wall across river; on overturned limb of westwardly-overturned anticline, as shown by bedding-cleavage relationships and reversed drag-folds.

90.4 to 91.8 Outcrops of sheared and overturned McKay in road-cuts; badly cleaved.

91.0 Good view of east face of Dogtooth Range on opposite side of Trench.

92.0 Descent into Rocky Mountain Trench; bedded gravels dipping towards Trench; primary dip due to rapid deposition westward into standing water in Trench.

92.4 Moberly Peak on right ahead, composed largely of westwardly-overturned and faulted syncline in Beaverfoot-Brisco limestones and Wonah quartzite. This syncline passes into Trench immediately northwest of peak.

93.9 Golden Lodge.

PART II - GOLDEN TO RADIUM

This portion of the route lies entirely in the Rocky Mountain Trench, along the west face of the Brisco (Beaverfoot) Range.

Mile

00.0 Golden Lodge.

00.2	Bridge over Kicking Horse River, which enters Columbia at grade a short distance to the west. Elevation (about 2575 feet) lowest of whole route.
01.0	Railway crossing; face of Dogtooth Mountains on west side of Trench, with dominant westerly dips clearly discernible.
01.1	Columbia River valley on right; river is graded, with average gradient of one foot per mile or less.
01.8	Golden golf course on left. Ahead and to left, large outcrop of McKay forming core of tight anticline overturned towards west.
05.1	Canyon Creek emerging from Dogtooth Mountains on opposite side of valley. Range here formed dominantly of Lower Cambrian quartzites and slates; contorted Middle Cambrian slates and sheared McKay group beds stretch below mountain front, not visible from road. Material brought down by Canyon Creek causes unusual restriction of Columbia to single channel in Trench.
06.2	Ahead on left, main Brisco syncline exposed in un-named large mountain; large cliffs are of Beaverfoot-Brisco.
06.8 and 07.2	Outcrops of cleaved McKay on left; where attitude determinable, beds are overturned towards west, on west limb of syncline.
07.5	Horse Creek; flows directly across main Brisco syncline on left.
08.6	Twelvemile Creek emerging from strongly glaciated valley across Dogtooth Mountains on opposite side of Trench; front of Dogtooth Range here formed almost entirely of westerly-dipping fault blocks in Lower Cambrian.
09.9 to 10.8	Outcrops of sheared McKay on left of road.
11.3	Good view of Columbia River on right; outcrop of sheared McKay on left.
11.8	Jubilee Mountain straight ahead in distance; structural continuation of Dogtooth Mountains to southeast, forming intravalley ridge within Trench.
11.8 to 12.8	Intermittent outcrops of sheared McKay on left of road.
13.7	Steeply dipping ridge of Brisco Range on left, formed principally of Beaverfoot-Brisco and Wonah formations; part of west limb of main Brisco syncline.
14.3	Sloughs, channel of Columbia River.
15.2	McMurdo; type locality of Beaverfoot formation nearly due east.
15.3	End of pavement.
16.5	Twin ridges of Jubilee Mountain clearly visible ahead towards south: type locality of Jubilee formation, exposed in tight syncline with McKay shales and Beaverfoot limestone in core. Jubilee is Western Range equivalent of Ottertail formation of Main Ranges. Note decrease in elevation of Dogtooth Range to right.
18.1	Southern end of Dogtooth Mountains on right; prominent cliffs of Beaverfoot-Brisco and Wonah formations in Brisco Range on left, on west limb of main Brisco syncline.
20.8	Ahead and to left, prominent cliffs of Beaverfoot-Brisco capping Brisco Range, on west limb of main Brisco syncline. On mountain ahead, Wonah quartzite occupies lower third on right; quartzite about 1200 feet thick at this point.

23.0 to 23.7	Parson, elevation 2592 feet.
24.6	Ahead and to left, panorama of Brisco Range, with dominant steep easterly dips. Crest of range formed of steeply-dipping Beaverfoot-Brisco limestones and dolomites.
24.8	On left, prominent wall of Beaverfoot-Brisco, with Wonah, Glenogle, and McKay below.
26.2	Beard Creek entering from left; drains crest of Brisco Range; valley little affected by glaciation.
31.6	Typical outcrop of well-bedded McKay at north end of Jubilee Mountain, on right. North end of ridge much cut by transverse faults with several trends.
33.2	Steamboat Mountain, more southerly of two intravalley ridges, straight ahead. Largely composed of synclinal ridge of Jubilee dolomite.
34.1	On left, cliffs of well-bedded, gently-dipping McKay near crest of anticline; main ridge in background consists of tight isoclinal syncline overturned towards southwest.
34.2	Harrogate Creek and Post Office; type locality of Middle Devonian Harrogate formation is in isoclinal syncline just below crest of ridge to left.
37.1	High point in road. Jubilee Mountain on right, with well exposed section on scarp-like eastern slope: upper three-quarters consist of Jubilee formation (2,000′ thick), lower part of which is well laminated and reddish-weathering. Lower slopes of mountain consist of thinly-bedded limestones and slates of Lower Cambrian Donald formation, underlain by more massive St. Piran quartzite. On left of road, Beaverfoot-Brisco limestones dip steeply to west and strike obliquely into Trench.
39.0	Note steep westerly dips in mountain ahead and to left; on east limb of syncline lying west of main Brisco syncline, and trending obliquely into Trench about at Spillimacheen.
41.2	Spillimacheen: STOP. Points to discuss: (1) Trench, Jubilee Mountain, Steamboat Mountain, front of Purcells. (2) Stratigraphy on Jubilee Mountain; relation to Dogtooth Mountains. (3) Stratigraphy of Brisco Range. (4) Structure: oblique trend of Brisco Range structures; necessity of fault between Jubilee Mountain and Brisco Range; inferred relation to Redwall fault; Beaverfoot-Brisco and Wonah in front of Brisco Range, dipping at 75-80° towards Trench. (5) Course of Spillimacheen River; really joins Columbia at Castledale, 10 miles north of Spillimacheen. Influence on west wall of Trench.
41.4	Road on right leading to Giant Mascot (Silver Giant) Mine; base metals in barite gangue in fractured dolomite of Jubilee formation on west side of Jubilee Mountain.
42.7	Galena Creek (called Fraling Creek on most maps).
42.8	On left and ahead, prominent ridge of Wonah quartzite midway up mountain. Part of major faulted syncline which is crossed by road east of Radium, between points 04.5 and 05.5 of next section of this road log.
44.4	Fine view of Purcell front on right.

47.3 Outcrop of Wonah quartzite on left, near road; on west limb of faulted longitudinal syncline which passes obliquely into Trench at this point.

49.4 Brisco Creek and gas station. Named for a member of Captain Palliser's expedition; has given name to range and to only Silurian formation in it.

50.0 North end of Steamboat Mountain on right; lower portion of Jubilee formation stands out by virtue of reddish brown weathering.

52.0 Pronounced gap of two Vermilion Creeks in range to left; two creeks drain crest of southern part of Brisco Range for distance of 18 miles along strike.

55.4 North Vermilion Creek (formerly Luxor Creek).

56.8 Red breccia of Redwall fault crossing ridge to right of peak straight ahead.

57.6 South Vermilion Creek (formerly Kindersley Creek).

60.0 Note change of strike in beds on left; Beaverfoot limestones, with thin Wonah and Glenogle below, strike almost east-west and dip north.

64.2 Ahead and to left, red breccia of Redwall fault crossing ridge and trending obliquely into Trench. South end of Steamboat Mountain on right.

67.1 Well developed terraces on opposite side of valley on right; prominent gap is valley of Horsethief Creek. Red-capped mountain to right of gap is Mount Forster; red shales of Middle Devonian on top; combined Beaverfoot, McKay, and Jubilee below total only 550 feet; equivalents east of Trench total more than 9,000 feet.

67.7 Small hoodoos on left.

67.9 Bridge over Sinclair Creek.

68.4 Radium Junction.

PART III - RADIUM TO BANFF

First thirteen miles are across strike of Western Ranges sub-province of Rocky Mountains. Route forms geographic boundary between Brisco Range (on left) and Stanford Range (on right), which are strike-continuations of one another.

Mile

00.0 Radium junction.

01.0 Wide bend in road; in bottom of canyon on left, outcrops of very fossiliferous Middle Devonian limestone, not visible from road. On right of road, note primary dip in gravels.

01.1 Sinclair Canyon: Beaverfoot-Brisco dolomite at both sides of western end, recrystallized and stained salmon pink by iron oxide; in fault contact with steeply-dipping to vertical McKay. Fault plane clearly visible on both sides; minor associated slippage planes stained reddish by iron oxide; really a zone of faulting with two principal faults, one dipping 30° west and the other 55° west.

01.5 Outcrops of well-bedded McKay limestone and shale on both sides of road.

02.0 Radium Hot Springs: STOP.

Points to discuss:

(1) Normal contact between McKay (on west) and Jubilee (on east).

(2) Hot Springs.

(3) Redwall fault breccia (Plate 11).

(4) Alteration zone in sliver of Jubilee dolomite.

(5) Resume of section and structure between Radium and Kootenay River valley.

02.2 Highly altered and recrystallized Jubilee dolomite on both sides of road. Bedding difficult to discern, but known from regional structure to dip steeply towards west.

02.3 Breccia zone of Redwall fault on both sides of road; by following along range, breccia can be seen to be vertical over 4000 feet of relief.

02.5 "Iron Gates" viewpoint; entering central fault block of Western Ranges sub-province.

02.6 Prominent cliffs of steeply-dipping to vertical Beaverfoot-Brisco on both sides of road; minor fault block only, occupied at surface by tight syncline overturned towards southwest.

02.7 Bridge over Sinclair Creek.

02.9 Steep easterly-dipping fault, faulting Beaverfoot-Brisco on west against McKay on east.

03.0 Cliffs on right of upper McKay, on west limb of major anticline.

03.2 Outcrop of thinly-bedded McKay on left.

03.3 John McKay Creek, in valley of which is type locality of Evans' McKay group. Over 4,000 feet of beds exposed in large anticline; Glenogle absent; overlying Wonah only 60 feet thick.

03.5 to 03.7 Ahead on skyline, view of Mount Sinclair, northernmost peak of Stanford Range, exposing excellent westerly-dipping section: Beaverfoot-Brisco on crest, thin band of Wonah below, thick Glenogle and upper McKay below that.

04.2 Sinclair Creek; first of series of outcrops of McKay on both sides of road, largely limestone; steep easterly dip, nearly vertical, on east limb of major anticline of central fault-block; sparsely timbered slopes, typical of slopes underlain by McKay.

04.5 Contact between McKay group and Beaverfoot formation, with thin intervening Glenogle and Wonah (actual contact concealed at road level); Beaverfoot consists of dense gray dolomite, dipping 75° east to vertical; Wonah is approximately on strike with that seen beside highway at point 47.3 south of Golden.

04.8 Westerly-dipping Beaverfoot-Brisco high up on left.

04.9 Probable fault, cutting out much of syncline.

05.0 Outcrop of Beaverfoot-Brisco on right, dipping west at about 20°, near axis of major syncline; thinly-bedded effect due partly to selective dolomitization. Outcrop locally sheared, intensely drag-folded, and stained reddish by iron oxide. Prominent ridge of Beaverfoot-Brisco ahead and to left.

05.2 Outcrops of Beaverfoot-Brisco on both sides of road, largely tree covered.

05.3 Bridge over Sinclair Creek, at mouth of Kimpton Creek.

05.5	On right of road, contact (concealed) between Beaverfoot limestone on west and Wonah quartzite on east; Glenogle shales underlie timbered hollows on right of road. Next outcrops to east are of McKay, on west limb of second major anticline in central fault block.
06.2 to 06.4	Outcrops of sheared and cleaved McKay on left.
06.6	Indian Head Mountain on right, exposing good section of gray Beaverfoot-Brisco, white Wonah, reddish-brown Glenogle, and light gray, thinly bedded McKay. These beds on upright limb of westwardly overturned anticline, and about on strike with gently-dipping McKay seen at point 34.1 of previous section, near Harrogate.
06.7	Warden's house.
07.1	Road cut outcrops of sheared limestones and shales of McKay group on left of road.
07.4	McKay as above, stained by iron oxide; near top of group.
07.6	Crossing longitudinal fault; breccia exposed on left; Indian Head Mountain on right, peak in Beaverfoot-Brisco limestones.
07.8	Sheared McKay on left, continuing around dangerous bend in road.
07.9	Last crossing of Sinclair Creek.
08.0 to 08.1	Contact between easterly dipping McKay and paper-thin shales of Glenogle on left of road immediately beside bend; Glenogle not particularly graptolitic at this outcrop.
08.2	Outcrop of sheared and recrystallized Beaverfoot-Brisco.
08.3	Olive Lake, draining eastward into Kootenay River. Outcrops of Beaverfoot-Brisco on left, in tight syncline (main Brisco syncline).
08.5	Sinclair Pass, 4,875 feet.
08.6	Approximate position of Stanford fault, not exposed; entering eastern fault-block of Western Ranges sub-province.
08.8	First view of Mitchell Range on far side of Kootenay valley; most peaks in it consist of Upper Cambrian Ottertail formation, with some overlying Goodsir, dipping at about 60° towards viewer. Prominent gap is that of Cross River; river is actually transverse section of Mitchell River, and drains Continental Divide from White Man Pass to Assiniboine Pass. Beginning about at this point, series of outcrops of sheared McKay (Goodsir) on left of road, continuing to 15.1.
09.4 to 09.7	Very highly sheared and chloritic McKay on left, ribbed by veins of quartz and calcite. Plane surfaces dipping 60° are cleavage planes; bedding steeper than this, i.e., 80° west overturned. Occasional drag-fold also shows bedding to be overturned towards west.
10.2	Very highly sheared McKay on left.
10.4	To right, view southward along east face of Stanford Range and down Kootenay valley. East face of Stanford Range composed dominantly of sheared Ordovician rocks in complex folds overturned towards southwest.
10.8	Large road-cut of highly sheared and phyllitic McKay; bedding dips 60° southwest, cleavage vertical. Viewpoint for Kootenay River valley on right.
12.3 to 15.0	Outcrops of chloritic, phyllitic McKay on left, approaching schist-zone of White River Break.

PLATE 24

Quarrying operations at Loder's Lime Plant, near Exshaw. Shows the pure,white limestone of the Middle Cambrian, with cliffs of Devonian above. Photograph by M. K. Sorensen.

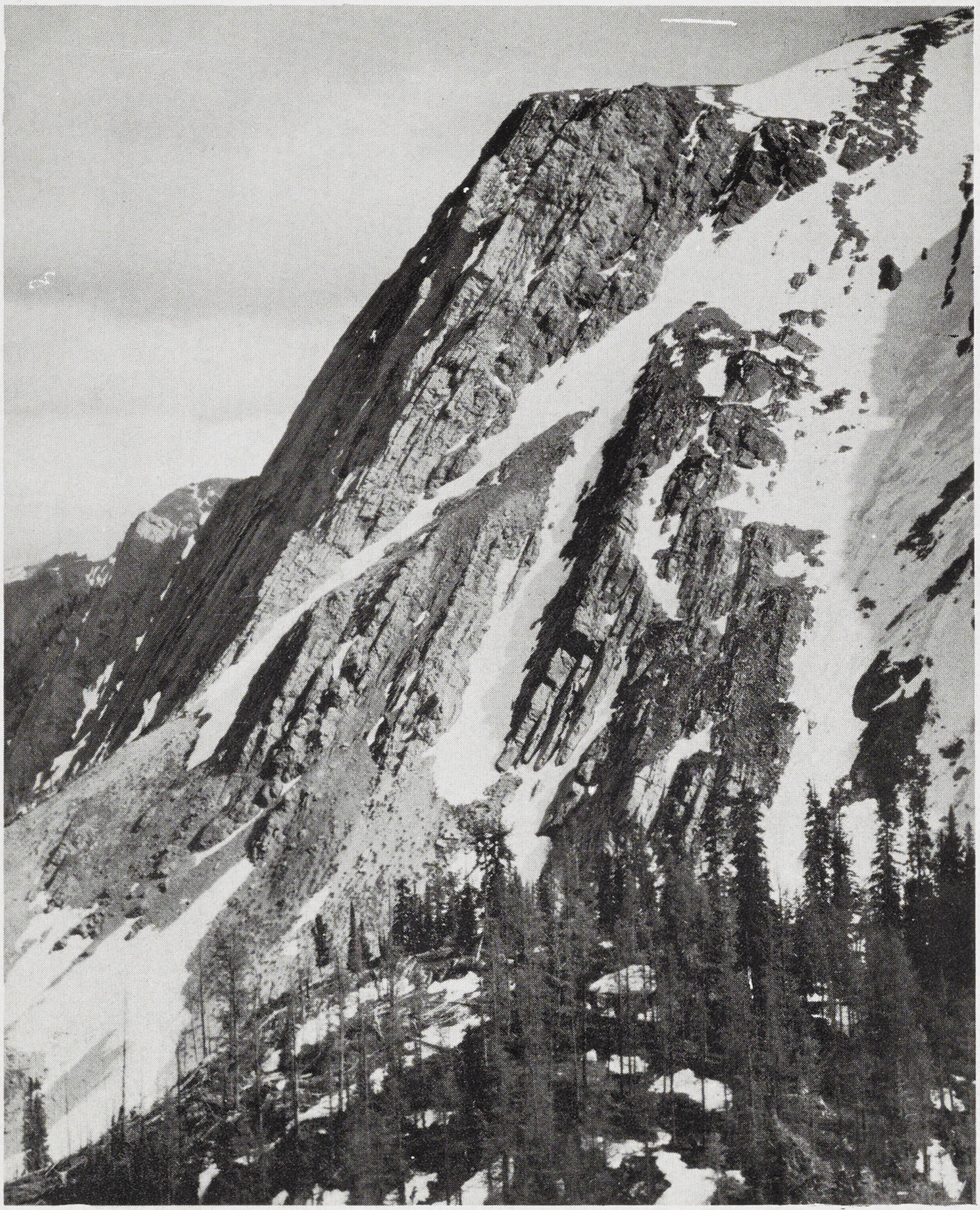


PLATE 25

Cliffs of steeply-dipping Beaverfoot-Brisco dolomites and limestones, showing feature-making nature. Pedley Pass section, central fault-block of Stanford Range. Photograph by F. K. North.

PLATE 26

Drag-folded arch in well-bedded Goodsir limestones and shales in the Mitchell Range. Photograph by G. G. L. Henderson.

PLATE 27

Looking northeastward at the entry of the White River into the Kootenay. White banks cut in pulverized schistose Goodsir (McKay) of White River Break zone. Note loss of ruggedness and elevation in southern Mitchell Range in background. Photograph by F. K. North.

16.0 to 28.3 Passing along strike of White River Break zone, separating Western Ranges sub-province on left (represented by Brisco Range) from western sector of Main Ranges sub-province on right (represented by Mitchell Range).

16.1 Kootenay River on right. East face Brisco Range on left; large syncline visible towards north; massive steeply-dipping beds are in Beaverfoot-Brisco. Prominent snow-capped peak in distance ahead is Helmet Mountain, composed of Ottertail limestone of "Rock Wall" capped by Goodsir group. South tower of Mount Goodsir just visible to left of Helmet Mountain. Washmawapta Snowfield lies partly on east slope of Helmet Mountain, and surface exposure of Ice River Complex immediately west and north of it.

16.6 Mount Kindersley on left.

18.0 Meadow Creek camp ground: LUNCH STOP. Mount Harkin on right, with Ottertail limestone dipping towards observer; highest peak in Mitchell Range.

20.0 Prominent un-named peak straight ahead, in Brisco Range, composed of almost flat lying Beaverfoot-Brisco limestones in axis of syncline; white weathering Wonah quartzite visible below, at timberline. Prominent peak on right is Mount Selkirk, composed largely of Ottertail limestone dipping irregularly at 60° towards observer. Other (east) face of this range is southward continuation of "Rock Wall" of Vermilion Range.

21.5 Signs to Mount Daer and Mount Selkirk, in Mitchell Range to right; gap of Daer Creek between.

22.9 Forest Service lookout tower; schistose McKay of White River Break in road-cut on right.

23.6 Dolly Varden Creek; Vermilion River enters Kootenay from right, after flowing nearly parallel to it for eight miles.

23.8 Mount Wardle, straight ahead, is southernmost peak of Vermilion Range; separated from its strike-continuation, the Mitchell Range, by transverse section of Vermilion River. Composed of westerly-dipping Ottertail and Goodsir.

26.2 To right, fine view of back slope of northern end of Mitchell Range. Prominent spire is Mount Selkirk. Watershed of range, southward from here to Cross River, is east boundary of Kootenay Park.

28.1 Warden's cabin.

28.3 Kootenay Crossing (altitude 3840 feet); immediately to right of road, chloritic, phyllitic Goodsir of White River Break.

From this point to 55.5, route lies within western sector of Main Ranges sub-province.

29.1 Pass through Vermilion Range ahead.

29.8 Highly sheared Goodsir on right, in footwall of White River Break.

30.2 Through pass to right, view of southern end of Hawk Ridge in next range to east; gap in Brisco Range to left is Luxor Pass, drained by North Vermilion Creek.

30.5 View overlooking Vermilion River to right; outcrops below are of phyllitic Goodsir in footwall of White River Break. Vermilion River here makes hairpin turn to southeast and flows through Hector Gorge before entering Kootenay.

30.9 Outcrop of sheared Goodsir on left.

31.2 Cable crossing of Vermilion River; outcrops of sheared Goodsir on both sides of river. Note extreme distortion of bedding in outcrops on south side of river, near holes. All plane surfaces are cleavage-planes. In outcrop on left of road, bedding dips very gently to west; main cleavage dips 60-80° southwest.

31.7 Basal Goodsir crops out on south bank of river; contact between Goodsir and underlying Ottertail limestone concealed at river level. Mount Shanks directly ahead, in southernmost part of Hawk Ridge.

32.0 Outcrops of westerly-dipping Ottertail limestone on south bank of Vermilion River.

32.7 Contact between Ottertail formation and underlying Chancellor group should cross road.

33.3 Mount Wardle immediately on left; contact between grey-weathering Ottertail and reddish-weathering Chancellor discernible in very pronounced gulley. Spar Mountain on right, composed largely of shales and limestones of Chancellor group.

34.1 Peak visible through gap to right is Split Peak, northernmost peak of Ottertail limestone in Mitchell Range; limestone strikes straight across road.

34.4 Bridge over Wardle Creek. Spike visible on left is part of true "Rock Wall" of Vermilion Range. Last good view of Mount Wardle.

35.8 Animal lick on right.

35.9 to 36.2 Outcrops of silky argillite of Chancellor group on left of road.

36.5 Simpson Monument on right; Simpson River enters Kootenay from east.

36.9 Highly cleaved Chancellor phyllite on island in river; beds here are in general in hanging wall of Ottertail River fault, which is presumed to be a westerly-dipping thrust fault.

37.5 Mount Shanks, to east, marks southern end of Hawk Ridge, which is cut off to south by valley of Simpson River. Hawk Ridge (Plate 10) consists of tightly folded anticline overturned towards northeast (away from observer). Two prominent massive beds, midway up ridge and converging towards northwest, represent single limestone bed in Goodsir group on upper and lower limbs of overturned fold.

40.4 Looking backwards (almost due south), view showing relation between Split Peak (largely Ottertail) and Spar Mountain (largely Chancellor).

40.7 Vermilion Crossing, 4145 feet: STOP.

Points to discuss:

(1) Mount Verendrye in "Rock Wall" due west; westerly-dipping Ottertail limestone.

(2) Ridge in westerly-dipping Chancellor.

(3) Shearing in Chancellor; bedding dips 2° to 5° west and cleavage 45° west. Suggestion of approach to crest of anticline overturned towards east.

(4) Hawk Ridge; necessity of intervening fault, lying east of highway.

42.0 to 43.0 Outcrops of cleaved Chancellor on both sides of road and of river; cleavage dips 45° west.

46.1 Trail to Floe Lake; lake lies at foot of "Rock Wall" (Frontispiece); part of Rock

Wall visible through gap in nearest range, which is composed of beds of Chancellor group, dipping southwest (away from observer).

46.3 Hawk Creek.

47.0 Triangular peak immediately ahead is Vermilion Peak, top formed of drag-folded lower beds of Goodsir group, overturned towards east. Part of range in hanging wall of Stephen-Dennis fault.

52.5 Numa Creek entering from left; drains glaciers south of Wolverine Pass.

53.1 Approximate inferred position of Ottertail River fault, thrusting Chancellor group eastward over Goodsir beds. Mount Gray through gap to left; part of "Rock Wall" of Vermilion Range, and is south wall of Wolverine Pass.

55.1 Cliff on left is in massive Ottertail limestone on Prospector Mountain, dipping west in hanging wall of Stephen-Dennis fault.

55.4 Bridge; Park Warden.

55.5 Marble Canyon: STOP.

Points to discuss:

(1) "Rock Wall" to west; position of Ottertail River fault.

(2) Stephen-Dennis fault; drag-folding on Vermilion Peak; note similar folding on Mount Haffner (sign shortly east of this point).

(3) Canyon; marmorization; potholes; drainage basins.

(4) Stratigraphy of ranges on two sides; resemblance to Field stop, when two opposing plunges taken into account.

(5) Marble continues, north of road, to 57.0.

From this point to 67.2, route crosses eastern sector of Main Ranges sub-province.

59.2 Upper cliffs on right are in Eldon dolomite; note unchanging appearance between this point and Cathedral Crags; middle grey band is Cathedral limestone; St. Piran quartzite largely hidden in trees below.

59.6 Face of Mount Eisenhower straight ahead; upper crags in Eldon formation; two lines of discontinuity across face due to Stephen (above) and Mount Whyte formations.

60.1 Continental Divide (5416 feet); real headwaters of Kootenay drainage system; leave Kootenay Park, enter Banff Park.

61.0 Basal Cambrian conglomerate exposed immediately east of Altrude Lakes east of highway; lakes drain eastward into Bow River.

62.1 Boom Creek and trail to Boom Lake; Boom Mountain on left, capped by westerly-dipping Cathedral limestone.

62.2 Summit of Vermilion Pass; highest point of whole route.

62.5 Storm Mountain on right, composed of Lower and Middle Cambrian beds on west limb of main Bow River anticline; tree covered slopes east of base of mountain underlain by Precambrian argillites and conglomerates. Dip slope of Sawback Range straight ahead; most of visible slope in Palliser limestone.

66.7 Bridge over Bow River; approximate position of axis of Bow River anticline.

67.0 Main line, C.P.R.

67.2	Castle Mountain junction.
	Remainder of route lies in Front Ranges sub-province.
69.5	Panorama of Sawback Range ahead, showing west face with steep westerly dips in Palliser and Rundle limestones; Pilot Mountain on right.
70.9	Pilot Mountain straight ahead.
71.1	Johnston Canyon; up canyon to left, excellent section of parts of Rocky Mountain and Rundle formations, not visible from road.
73.7	Sign to Mount Ball, through gap to right; view ahead along strike of Bourgeau Range, which is strike-continuation of Sawback Range.
74.8	Tree in road.
77.5	Dip slope of Palliser on west face of Sawback Range ahead.
80.1	Bends in road around rib of Palliser in Sawback Range on left; good view along strike of Bourgeau Range ahead; two ridges on right of Bourgeau Range are formed of Rundle and Palliser limestones; main rib in centre of Upper Cambrian Ottertail limestone. Notches eroded in (from right to left) Banff formation, Fairholme and McKay formations, and (on far left) reddish-weathering Arctomys shales.
80.6	Fairholme of Sawback Range on left; note vugs in road-cut outcrop.
80.8	Typical well-bedded limestones of McKay on left; note similarity to equivalent beds in Brisco and Stanford Ranges; "Goat Range" sign points directly at these beds.
81.6	"Sheep Range" sign points to rib of Ottertail limestone, forming crest of Sawback Range, including Mount Cory.
83.2	Mount Edith visible through gap to left; nearly vertical Palliser limestone on east limb of faulted anticline.
83.9	High ridge on left is Palliser limestone on Mount Norquay (third range at this latitude).
84.4	On left, ribs of Rundle and Palliser on Mount Norquay, with brown weathering Banff between; Sulphur Mountain on strike across river (Plate 5).
86.3	Banff railway crossing.

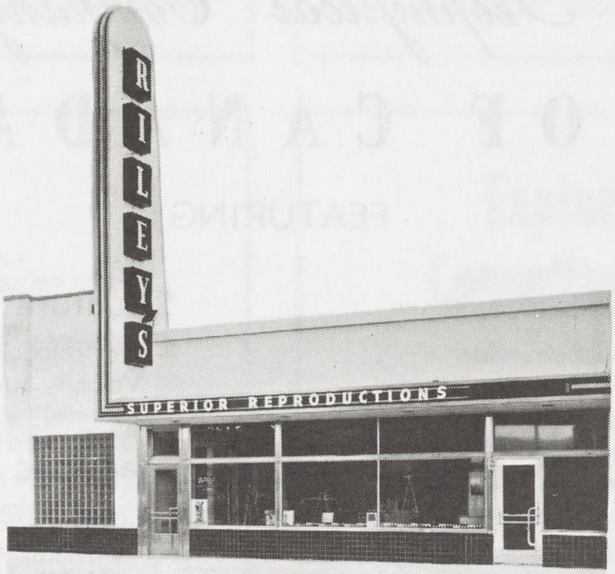
END OF LOG

"Curly" Minor sez . . .

"During spring round-up we managed to lasso the strays and get 'em in one corral.

Here's a picture

of the new main gate . . .



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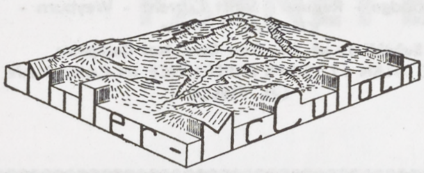

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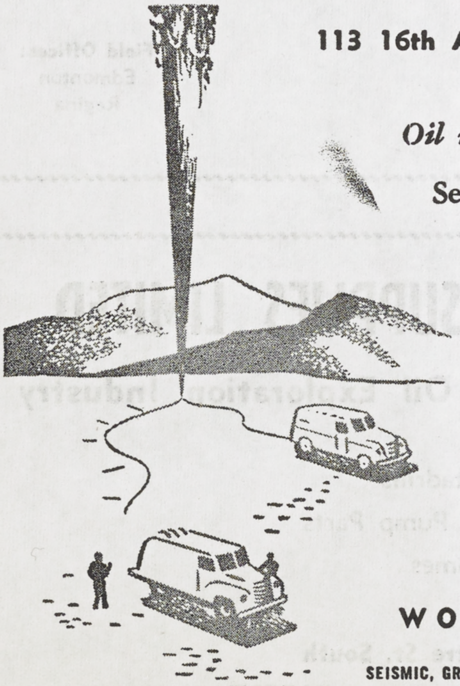

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